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Buffer Region: Reifying Buffer Analysis for GIS Professionals

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Gif-sur-Yvette, November 25, 2019

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ABSTRACT OF
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<p>Geographic Information System (GIS) is widely used by professional map makers for supporting tasks such as decision-making process. However, GIS has been considered as hard to use and not user-friendly and remains unchanged for decades. In my thesis, I am aiming to find out design solution that help GIS professionals in using GIS. I interviewed 13 professional map makers to understand tasks performed by professional users and problem they have. I found out three problems professional users have with GIS: Lack of support for exploration, hard to learn and use for early career professionals, and lack of support for customizing visualization; two strategy they used: visualizing data for understanding and getting feedback, and overlapping for analysis; and two patterns across their use of tools: they use distance as core criteria and their object of interest switch between layer and elements within layer. Based on my interview result, I iterated my design with three prototypes: mask focusing on reifying methods applied to layers to reduce repeated work and support exploration, bubble focusing on reusing the parameters to reduce repeated works, and finally buffer region reify the process of creating buffer area with direct manipulation, for supporting early career users and user task of exploration.</p>			
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Chapter 1

Introduction

Thematic maps have been widely used by geographic professional for analysis and decision making. While traditional reference maps record mainly geological information such as shape of roads and lakes, and boundaries of cities for locating, thematic maps focus on emphasizing spatial pattern of one or more spatial attribute[40]. For example, a thematic map would describe the population of different arrondissements in Paris while a reference map would show the topographic information of the city. By visualizing data with special theme onto map, geographic professionals are able to discover patterns or relationship related to geospatial data. One of the most famous example is that in 1854, John Snow visualized the location of death of cholera and location of water pumps on a map of London, and found out how cholera was transmitted[42]. Since then, thematic map has been serving as a powerful tool for analyzing geographic data.

Geographic Information System(GIS) is a system to capture, store, interact with, analyze, present spatial data[8], and is used by professional map makers for making thematic maps. Arc GIS¹ and QGIS² are the two main software in industry that professional users used for making thematic maps and spatial analysis. Arc GIS is a mapping and analysis platform on Windows System for GIS professionals to conduct multiple tasks: conduct spatial analysis for analyzing data, create map and visualize data onto map, manage and collect different types of data³. QGIS is a free and open sourced software on multiple platform including Windows and Mac that have also been widely used for map making, geovisualization and spatial analysis, while it supports less analysis and visualization methods than Arc GIS.

¹<http://www.esri.com/software/arcgis>

²<http://www.qgis.org>

³<http://www.esri.com/software/arcgis>

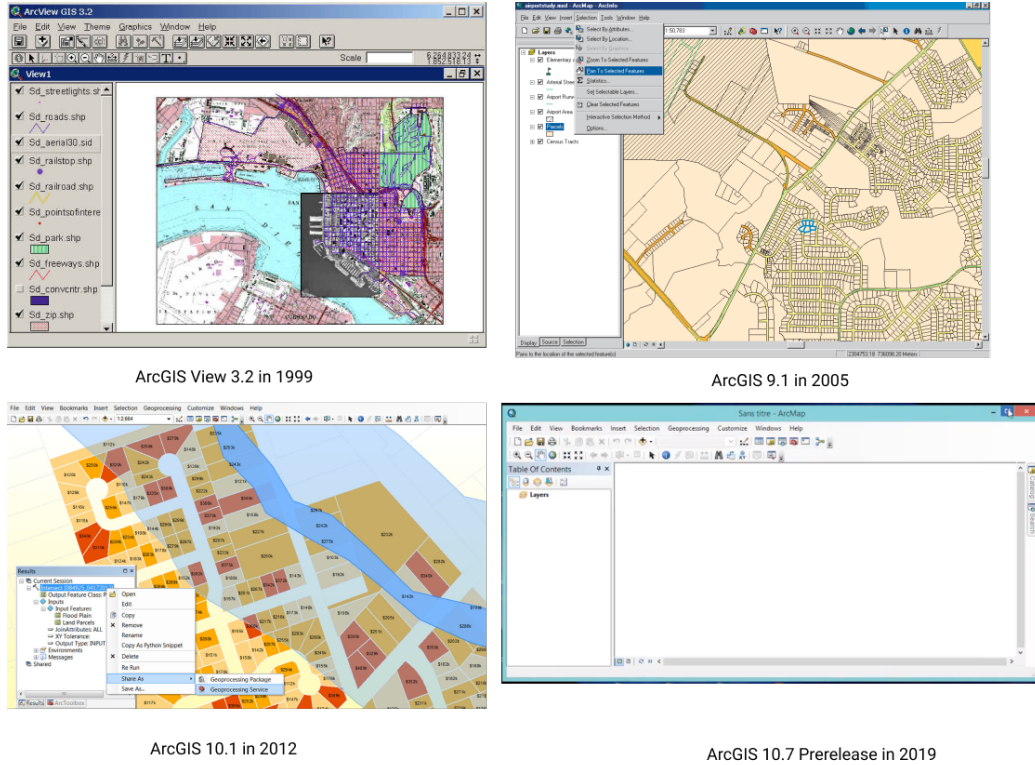


Figure 1.1: Change of ArcGIS interface

However, ArcGIS and QGIS have remained almost same in their interface and how users interact with the provided tools for the past decades. As can be shown on Fig 1.1, the layout of the interface and tools it provides in the interface remained almost unchanged in ArcGIS in the past 20 years. It is noticeable that the interaction in ArcGIS and QGIS still relies on navigation by menus and issuing commands by selecting items in drop-down boxes and specifying values in pop-up windows. These interactions are widely accepted and easy to understand, but they do not always fit with the requirements from GIS professionals. GIS has long claimed to be hard to use since it was born even for professional users because the interface of GIS is built from the point of view of how programmers constructed the system instead of how users use it for their own works[41], yet the core design of the product itself remain unchanged. Also, the context of use of GIS has been changed over the past 20 years, making interactions in GIS do not fit with the current work of GIS professionals. With the improvement of technology, especially in computer science, there are more types and bigger amount of data GIS

professionals can collect and make use of, compare to what they used for making maps in the last decades. GIS Professionals are now working with large data set, multiple sources of data and different scale of focusing area that is different from what traditional spatial analysis methods are originally designed for[23]. Therefore, I am motivated to focus on providing design solution that is designed on the user point of view and under the new context of work of GIS professionals that could help GIS users in conducting their tasks.

Urban planning is one of the main application area of GIS[45]. With the expansion of urbanization⁴, there is also a rising interests focusing on urban design. While there are multiple research focus on multiple areas in urban planning including relationship between designer and citizens[16, 18], urban design and data[15, 17], and some others focusing on novice GIS for citizens[35], there isn't much research focus on how urban planners are using GIS to design the city and how to create a better tool for them.

In summary, GIS has been widely used for making thematic maps to support decision-making process, while the interface remained unchanged and hard to use for decades and therefore does not fully support GIS professionals. Also, urban planning is one of the main GIS application domain, while little research in urban planning focus on improving GIS. Therefore, I am motivated to focus on the research question of how to design a tool for GIS professionals, such as urban planners, to supports their tasks while map making.

After reviewing related work, I present a study of interviewing with map professionals to explore what are the tasks they have, how do they use GIS to complete their tasks, and what problems do they have while completing their tasks. I found out three problems GIS professionals have, two strategy they used for conducting their tasks, and two patterns of how they work with GIS. Based on my findings and design guidelines from instrumental interactions[4], I explored design solution by iterating with 3 design alternatives Mask, Bubble, and Buffer Region, and implemented my final design concept for further evaluation. After that, I also introduced 3 scenarios where Buffer Region could help with GIS professionals.

⁴<https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html>

Chapter 2

Related Works

In literature review, I focus on research about interaction with maps and how map makers create maps. In most GIS, from Google Maps to professional GIS such as QGIS and Arc GIS, users interact with map by panning and zooming, or setting up queries by filling in parameters in pop-up boxes or typing text and setting up fuzzy search. However, as there are different types and massive amounts of information in maps, such interaction does not fully support user tasks. Researchers have carried out works in empirical study about how people interact with GIS, creating geovisualization techniques to improve the usability of created maps, and interaction techniques that can be applied to GIS and other multi-layer structured systems.

2.1 Empirical Study

Focusing on how novice users would use different GIS systems, Samason and Sumi[38] conducted an empirical study on how driver are following recommended routes, and they found out that drivers are tend to not follow recommended routes in familiar zones as they prefer to reach by their familiar or regular routes. Pang et al. [35] designed a system called City Explorer and observed how transit commuters use city explorer for sharing and discovering local information. They found out that while people do enjoy getting to know more about the city, they are more keen to receive information that affected their trip but not prefer to get to know activities or other information during their commute time. Both provide insights on users preference on user preference when interacting with information on maps, while they are focusing more on context of non-professional GIS users and give less insights on how would GIS professionals react in similar context.

Haklay et al.[20], focusing on the task of novice users, conducted studies to evaluate the efficiency on users using Web Map for querying and searching task. They found out that the larger the map area is, the more efficiency the interface will be. While this finding provide design guideline of amplifying map area, it has been an strategy of GIS interface and doesn't provide much implication on how to arrange other tools GIS users use to interact with the map.

Focusing more on professional users and their complex tasks, Med and Křemen[32] conducted a study on how professional users issue complex queries over multiple data sets for urban planning. They found out that urban planners use combination of standard queries and spatial queries, and give insights on how to design query tools for urban planners, while it is still restricted to interacting with map by pop-up windows.

Wilson et al. [44] focuses on modeling professional users when making geovisualization in their analysis or decision-making tasks. They formed a map interaction framework for geovisualization, which includes four user goals: explore, analyze, synthesize and present, and the operation, user type, action, data type, active data results accordingly. They also noticed that there is differences between novice user and experts user, that experts user have a clearer mind on forming a strategy using multiple tools for completing the same task. However, this study only focus on the geovisualization process and only in GIS, while many GIS professionals also conduct other types of tasks in other places.

Although there are similarity in tasks performed by novice users and professional users that they interact with map for carrying out similar tasks such as spatial querying, professional users take different tasks and use different strategy for achieving similar goals. Also,these research focusing on professional users are mainly focusing on the task of querying while querying and searching are only part of professional users' task. It would be interesting to also understand other tasks that are performed by professional users, no matter they are within or outside GIS to get a clear overview of how they perform their tasks, why they need to complete their tasks outside GIS, and what GIS fails to support them.

2.2 Geovisualization

Many research are focusing on improving geovisualiztion and applying geovisualization in different discipline.

2.2.1 Improve geovisualization

Researchers have conducted multiple solution for helping people with transition of different styles of geovisualization. Ory et al.[34] designed a transition algorithm for helping users navigate themselves between the transition of two topographic styles. Hoarau et al. [21] explore how to design a continuum visualization between orthoimage and a topographic map for helping professional users' task of mixing different types of maps. Lobo et al. [27] focus on using animation plan to design a customized transition animation between two satellite images in order to help map makers in their task of analyzing temporal data. These techniques helps with viewing different visualizations and analysis that are relying on viewing a sequence of data. However, as they focus on the specific problem of transition between different data, they are hard to be applied for some of the GIS professionals when they are only working with one kind of geovisualization at a time.

Luz and Masoodian[29] explore how adding a semi-transparent layer could help with the analysis task and determined a design guideline that 50% transparency can help users in both reading the background map and manipulate the interface elements in the foreground layer. However, this implication is still based on the task of "reading map" instead of actually interacting with elements on map when overlapping layers, which is one of the main task for GIS professionals.

Research has also been done in analyzing differences between traditional cartography and online map[39] as well as differences between bespoke map and reference map for extracting design implications for geovisualization. They focus on reference map, which is different from thematic map as the latter one also requires using colors to visualize data, or visualize raster data that are harder to find in the design of reference map.

Geovisualizaiton has also been used for better support navigation for driving as well as route viewing. LineDrive [1] is a system for designing and generalizing the rendering route layout to improve route map readability.

LineDrive is designed for the task of using maps for following a pre-defined route displayed on map. However, as LineDrive only focus on the selected route, users are unable to get contextual information to determine their precise position or choosing another route. Wang et al.[43] provide a map that generates route tree for navigating users while viewing different scale of route maps. Map using Route Tree can help users to navigate between different scale levels and different position in a map by determining the complicated spots where users need to turn or change directions beforehand. Route Tree can reduce the cost of users' interaction with the map and help users with their navigation task on maps with higher efficiency. Similarly, this is also an interaction that designed for viewing the map, without further interaction such as selecting or adding data.

2.2.2 Geovisualization for different disciplines

To enrich geovisualization, researchers also focus on enriching objects for visualizing and methods for supporting geovisualization.

Traffigram[22] is a system that visualize travel time on map in order to provide more effective geovisualization. By visualizing travel time onto map, viewers are able to determine which place is closer by directly viewing the map. This visualization provide circle with different diameters to indicate different travel time, which is not realistic as it didn't consider differences between travel tools or the length of the actual roads. It only provides very rough comparison between travel time. This make it hard to be utilized by the professional users who requires a more detailed analysis result.

NewsView[19] is a visualization tool that designed for generating a thematic map according to how the location being mentioned in news. By visualizing news onto map, NewsView support trend identification and data comparison relevant to a given news article. NewsView can automatically generate an annotated map, this is a map with simple geovisualization for mainly comparing data mentioned in the news.

2.2.3 Methodology of geovisualization

Some other researchers focus on how to conduct geovisualization and provide insights on designing tools for geovisualization:

Prado et al. [37] analyzed the differences in symbol and visual elements that are being used in traditional cartography and geographic information systems and found out that in GIS there are more symbols being used compare to the traditional cartography.

David Lloyd and Jason Dykes[25] conducted research in how HCI approaches are being used in geovisualization design, and how effective they perform in helping with the design task of designing a map. They found out that although HCI approach has seldom been used in geovisualization design, the technique of applying scenario for understand the context of use as well as prototyping the final design could help map makers in their process of designing the map.

2.3 Interaction techniques

In current GIS, whether it is designed for novice users such as Google Maps or designed for professional users such as Arc GIS, whether it is a desktop software, a web-based program, or a mobile application, users could only interact with the map with limited methods including clicking, panning, zooming, or text-based queries. Many research explores how to enrich interaction with maps for different tasks and different interaction techniques.

2.3.1 Viewing the contextual information

RouteLens[2] is a techniques that help map users in exploring the neighbourhood of certain route using focus+context technique. The design of RouteLens succeeded in eliminating panning and zooming for viewing details of neighborhood area on map by making the lens for viewing detailed information focus more on the pre-defined route then the surrounding environments.

On the other hand, Jellylens[36] is yet another solution also using focus+context technique that supports users requirement of exploring a certain region and see detailed information by creating a transformative lens that can transform into the shape of the supposed focused region and thus give less information of the environment as well as helping users to easier find their focusing context when viewing details.

Both RouteLens and Jellylens are designed for supporting user task of zooming and navigating users on map. However, they display all the required information, whereas map makers must look for these in different files and layers. This makes them hard to support more complex searching and exploration tasks that require information that cannot be shown or interacted with on a single map at one time.

2.3.2 Supporting spatial analysis tasks

Focusing on the spatial querying task, Kumar et al.[24] designed a interactive system for spatial comparison task. With their system, users are able to interact with the map by first drawing out a region for comparison, and then draw multiple optional regions and compare them by viewing the similarity between POIs(Point of Interests) through pie chart or see similarity in color. The system could also help users in generating a heat map for evaluating all the regions on map. This interactive system allows users to obtain information that is hard to obtain through traditional spatial query and thus help users in their decision-making process. However, this system is limited to compare the composition of different categories of POIs, and do not supports other types of comparison.

Ardissono et al.[3] added a transparency slider to control the display of filter result by categories in both 2D Map and 3D Map. It helps to navigate users in their filtering results when there are a large amount of search result displayed on the Map. However, as it can only control the transparency of a whole category, the information overload issue would still exist if the query result is cluttered in one or two categories.

Lobo et al.[28] conducted an evaluation on the five kinds of map comparison techniques that cartographers frequently use. Comparing two orthoimage or two different maps is a frequent task among cartographers. Lobo et al. discovered that Translucent Overlay technique is the best technique among all tasks. This work give design guidelines on how to recruit map comparison technique when GIS involves comparison tasks.

Focusing on enabling users to explore multiple thematic maps and maps made in different time, Miguel et al.[11] described a system designed for helping users with searching for maps and overlapping maps for expert tasks. However, as the system only support overlapping maps on top of each other, consider that users would be interested in the overall area that are stored in

a map and ignore the problem of when overlapping maps with different scales some maps would be really small and hard to view, it doesn't support expert users tasks such as focusing on one research area among multiple maps and sorts of data.

MapMosaic[26] is another system that designed for helping expert users in overlapping maps with any preferred shape and area for their analysis tasks. MapMosaic enables users to work with multiple layers of map at the same time while focusing on their task and eliminating information displayed that users are not interested in. However, although MapMosaic supports overlapping both vector and raster data, it didn't support other spatial analysis methods that professional users use for processing their data before overlapping maps as well as other different overlapping methods that expert users use beside simply overlapping the image of maps.

2.3.3 Affective Visualization

To meet the broken link in user could not affect visualization on map and to help people collaborate on maps, Giaccardi and Fogli developed a system in which users could also give feedback on the data other people uploaded. This visualization help users to give feedback and encourage users to upload data that have good feedback.

Writing and touching Matulic et al.[31] designed a GIS interface that use pen-input for spatial querying on tablet. The system supports multi-criteria queries among city, region and path. Users are able to write down commands with pen on the map, and then determine the region by drawing a region, a line or without determine the region. Although this technique supports multi-criteria querying in the way that users can search for multiple regions with different criteria at the same time, it doesn't support to setup two criteria for the same region. Also, this tool can only supports exploration focusing on POIs and cannot be used for more complex spatial queries that involve not only searching for some category of POIs.

SpaceTokens[33] is a widget designed for mobile application that make locations sustained on the screen. By adding a widget to represent a location, users are able to locate the map or design a route with multiple locations. With SpaceToken users could compare the distance between multiple POIs easily, and change the route easier. However, users still need to specify the exact location while using SpaceTokens instead of having ability to explore the

nearby POIs and cannot use it for comparing other objects like area or roads.

2.3.4 Interacting with layers

Toolglass& Magic lens[6] are two widgets for interacting with multiple layers based-on see-through technique. Toolglass appears when clicking on the objects and provide multiple tools overlaid on the applied objects for user to select. By Toolglass users are able to interact with the object with easy access to multiple tools while magic lens provide an overview for users to compare the two parts at the same time. Although ToolGlass enable access to multiple tools, when there is too many tools as in GIS, such kind of interaction technique would still be hard for providing user a quick overview and select between those tools.

Excentric labeling[12] is a technique for labeling data dynamically when there is a large set of data. Users see labels by using mouse to move close to the points in the view, and labels will be generated automatically when the focus of mouse is close enough. This algorithm help solve the problem of information overload when there are a large amounts of data that needs labeling on the screen. By applying dynamic labeling technique it is possible to help navigate users when exploring a large amount of POIs on map.

2.3.5 Interacting with 3D Map

Danyluk et al.[9] applied the Look-from camera technique for navigating users in 3D map. They compared 3 different look-from techniques in their experiments and gathered design implication for applying the look-down technique into navigation and figured out that the discrete look-from-at technique works the best.

Debiasi et al. [10] designed a 3D traffic-flow stimulation system that enables user to interact with the map by drawing polygons to stimulate the transportation flow. This system shows possibility in how 3D map could help with visualizing the context for analysis process in urban planning.

Both of the research give design implication on how can 3D map enrich geovisualization as well as interaction in improving. However, as the main stream in industry is still focusing on 2D maps and urban planners present their analysis and visualize tasks more often in the 2D maps, I decided to

focus on the 2D maps in this thesis.

Although many works are done in modeling user tasks and studying their behavior in interacting with GIS, few of them have focus on the whole process of map makers' work, which also include works that are performed outside GIS. Also, although there are multiple tools for helping users interacting with map, they are mostly built for better viewing map or built for novice users, which do not apply to urban planners as they have more complex tasks than novice users, or they only focus on spatial querying while GIS professional also perform many other tasks.

Chapter 3

Methods

In my thesis, I am mainly focusing on how to gather insights from interview study and develop design based on user problems in the real world. Therefore, I selected and used the following methodologies for conducting my empirical study and prototyping.

3.1 Critical Object Interview

Designing for map makers from a user-centered approach requires a detailed understanding of how they actually work[13]. Interviewing GIS professionals about maps they recently made allows researcher to collect details from actual stories. This supports digging deep into their actual problems and capturing the complete workflow of map making, which helps in deciding where the design could take place and what are the problems unsolved.

Critical incident interview technique[14] requires interviewee to report critical incidents: examples of extreme behavior with a special significance for the observer of an activity that happened recently. Critical incident technique helps researcher to collect stories and facts rather than general opinions. As interviewees report from their memory, the request of reporting the most recent incident helps interviewees to remind and give examples as detailed as possible. Facts and details of how users interact with the system help researcher to understand how users work with the system and what problems they have, and therefore help researcher to develop design that is based on actual user requirements.

In my work, I used critical object interview[30] for conducting interview, which is a variation interview technique of critical incident interview tech-

nique. Different from critical object interview that require participants to report the last critical incidents, critical object interview ask interviewees to report the critical object that they made or interact with the system. Interviewees are asked to report what is the object that they made or interact with and how they made or interact with this object.

Map makers tend to organize and recognize their work according to the object they made instead of the events that happened between them and the system as mostly they are making a specific map or working on a specific project. Therefore, I use critical object strategy for interviewing to help map makers better recall their memories and give more detail on how they interact with the system.

3.2 Thematic Analysis

I use thematic analysis[7] for analyzing collected data. Thematic Analysis is an analysis method that has been widely accepted in both psychology and HCI. With thematic analysis, researchers need to first familiarize themselves with their data, and then going for an iterative process of coding and categorizing their raw data according to their own research interest and the collected data. Thematic Analysis is similar to grounded theory in how researcher iterative process of coding and categorizing. However, thematic analysis provides more flexibility for HCI researcher than grounded theory approach because it is not aiming at generating a theory of behaviour, but to provide insights for design. In my thesis, I used thematic analysis for both familiarizing and understanding my data and identifying design opportunities.

3.3 Video Prototyping

I used video prototyping[30] for creating prototype and collecting feedback. Building an actual and functional prototype is time-consuming, and video prototype allows me to explore and stimulate my design in a short period and collect feedback. By using video prototype, I first draw out a storyboard of how users would interact with the prototype and then create a paper prototype for making video. Compare to the traditional paper prototype, video prototype allows me to present my design in more detail and with complex interactions. As I have multiple prototypes to build and to collect feedback, I decided to use video prototyping technique for building my prototype.

Chapter 4

Study: Interview with Professional Map Makers

As there isn't much work done in understanding how professional map makers work except the part of querying and geovisualization, I am interested in understanding the task that map makers perform, the tools they use for, and problems they have while working with GIS software, especially urban planners on how they use GIS for supporting their decision-making process to find out design opportunity. In this study, I conducted interviews using critical object technique[30] with professional map makers. In my interview, I focused on breakdowns, workarounds, similarity in tool and tasks for looking for design inspiration.

4.1 Participants

I interviewed 13 professional map makers(7 female, 6 male). 5 participants work in urban planning, 1 in transportation planning, 6 in geovisualization, 1 in environmental engineering, and 1 in data science. Interviewees have different level of skills in using GIS software: 3 beginners with 6 months - less than 1 year experience, 1 with experience for more than 20 years, and others in intermediate level with more than 2 years experience. Although there are multiple kinds of GIS software available, most of the interviewees use Arc GIS or QGIS in their works, with one exception using MapInfo(p4).

Participants were recruited by reaching out to fellow students who have studied in related fields and students who are currently studying in the fields. Participants are not compensated for participating in the study, except for cookies and chocolates provided after the interview.

4.2 Procedure

Interviews are performed remotely(8) and face to face(5), with an average time of 40 minutes.

4.2.1 Preparation before the interview

I use critical-object technique for conducting my interview, which is an adjusted interview technique originated from critical incident interview[14] designed for interviewing people who work with a specific object at each time. By using this method, participants are requested to bring the last object they made with GIS software before the interview and will be asked to walk through their steps of making this object during the interview.

4.2.2 Explanation, Consent form and pre-questionnaire

Each interview starts with a five-minute introduction of the purpose of the study, and questions that we would go through. After the short introduction, I explain the consent form and about their rights in the study. Participants are then asked to sign the consent form, and I would also ask possibility of sending me a copy of their work.

After signing the consent form, there is a pre-questionnaire for participants to fill. The pre-questionnaire is about participants' background, their experience with GIS software and the kinds of GIS software they use.

I started to use pre-questionnaire in face-to-face interviews after P4, in other cases (interviews before P4 and online interviews), the interview will start by asking participants background, software they use and their experience with those software.

4.2.3 Step-by-step description

Participants are asked to show the last object they made with GIS. The interview is then based on the last project that they explained to me. I ask them to describe how they made the last object step by step and as detailed as possible. Participants are requested to tell me the steps they take of making that (or those series of) maps, problems they met during the process of making it, other tools and software they use and problems they have met throughout the process. Participants are also asked to describe where they think they met problems during the process or where they think the tool they used doesn't meet their requirements. As most of the tasks participants perform require a long performing time (e.g. for P5 it took 3-4 hours for

using one single tool), I do not ask them to go through their tasks again during the interview. Participants are also allowed to present maps that are not lastly made by them to explain the problems they have met.

4.2.4 General problems

After describing the work of most recent project, I ask participants the following questions:

1. other problems they found their general use and learning of GIS software;
2. tasks that they perform outside GIS software when working on other projects; and
3. overall comments on different GIS software or other tools that they use.

4.3 Data Collection

2 interviews are video and audio recorded, other 11 are audio recorded. During the interview, I also recorded by hand-written notes. Photos, screen shots or the final map or interaction with software are collected during the interview or sent by mail after the interview. Interviewee's general background and experience with the software are collected by filling a pre-questionnaire.

4.4 Data Analysis

I use Thematic Analysis[7] to analyze data collected from my interviews. Interviews are transcribed in audio or video into plain text, and went through after transcribing. When going through the transcript, I marked down patterns, interesting action interviewees perform, purpose, task description, problems they met and switching tools with highlighter. I then put these highlighted notes onto sticky notes, with page number, participant id, and number of notes on the page, and sort them roughly to find a coherent theme. After viewing and sorting the data for the first time, I go back to review the transcript looking for missing points, and go through all my notes to combine similar ones. After reviewing, I go through the previous themes again and reform my themes based on user tasks.

After taking a look at their general tasks and tools they use, I go through my post-its notes for the third time to extract breakdown and workarounds, and sort them by following the timeline of map making process.

4.5 Map making process



Figure 4.1: Map making process

To better understand how professional map makers work with geographical information, I analyzed what and how they perform tasks in GIS system. I analyzed their workflow by writing down steps and tasks participants perform and categorize them into 4 main steps shown in Figure4.1.

Figure 4.1 shows a typical process of how professional users making maps.

1. Collecting data: This is the first step of the map making process. Urban planners and other map makers do not produce geographic data, but rely on data produced by cartographers, other institutes or their clients. Interviewees found their data from:

1. open sourced files created by others;
2. data collected/provided by customers/professor;
3. data shared within the company;
4. data collected by themselves.

Most of their projects involve multiple types of data. They mainly collect the following 3 types of data:

1. Vector data stored in Shapefile or geojson file,
2. Raster data such as satellite images (Remote Sense image) or paper maps,
3. text data that are stored in spreadsheet.

2. Pre-processing data:

Map makers visualize multiple data onto their map. *“Because of the trend of big data, we are also using GIS to support us (in) making design (decisions) based on statistic ”(P4)* GIS professionals are also applying multiple kinds

of data collected by other institutions onto their map for supporting with decision-making process. They need to pre-process their collected data before apply further analyzing methods. Participants perform four kinds of pre-processing depends on their tasks:

1. *Transfer between vector and raster data.*

P5, P10 transfer their vector map data into raster data to perform per-form reclassify and density analysis methods later on. This is mostly done for performing specific kinds of analysis method that require raster data as their input. P2, P3, P7 and P11 mentioned that they manu-ally transfer raster data into vector data for geography calibration and vectorize remote sensing (RS) image or raster maps.

2. *Specify locations*

To use the collected data and visualize them onto the map, P1 and P3 need to co-relate their text data (e.g. GDP) to specified locations, such as city names.

3. *Filter data*

Participants also mentioned that they need to filter data before they started analysis. P4 and P9 got data larger than their focus area, and therefore filtered their data to a smaller scope. In P10's case, she should have all collected data in positive value, but there were some with neg-ative or empty value due to technical issues. She removed these outliers before she started her analysis process.

4. *Simple calculation*

For P4, he needed to visualize bus routes on the map, but he only got raw data in bus schedules describing which bus will passing by which stop at what time. He calculated number of buses passing by at each stop, and the rate of bus skipping the stop versus buses stopping according to the bus schedule.

5. *Define data set*

P5 need to analyze transportation accessibility to the same area by different transportation tools, he specified types of roads that different transportation tools can go through, for example pedestrian roads and roads for bikes or cars, and give them different speed limitation. He put these roads in 3 different data set, so that he can use them separately as input for his analysis method.

3. Data Analysis & Visualization:

Participants visualize their data onto the map and apply different spatial analysis methods. The analysis process is usually accompany with the visualization process. Map makers understand their collected data by visualizing them on map. For example, P3 and P4 visualize their data on map *“to understand my data and figure out where which part have problem and what is the problem”*(P4), *“to see where is different from [have different patterns] its neighbourhood and that will be my research area”*(P3). Other participants mentioned that they first perceive data by visualizing them on map, and then go between their data processing tool and the map to adjust their data processing & analysis methods.

4. Polish Map:

Although the visualization has been already done, map makers still need to polish their maps. They polish their map for two main reasons: to create better visualization for presenting(7/13), and to add other essential elements such as legends and title to their map(11/13).

Participants adjust map visualizations for the following reason:
Better style and color:Participants generally think the style and color of the original map created in GIS is not visually good enough for non-professional readers to view and understand the map.

“I feel like the map in QGIS is more for analysis but not for presentation... I would never show them to my clients...”(P9) 4 participants also mention that they need to unify style & color across multiple maps when they are making a series of maps.

Customize Visualization: For P1 & P5, they customize their own visualization for presenting data. *“The default pie charts provided by Arc GIS is too ugly... so I go to Excel and make every pie chart by my own.”*(P1)

P5 didn't explain why he chose to make his own visualization, but he created his own symbol for presenting multiple criteria he used for scoring a neighborhood region in Shanghai city. P3 used a plug-in tool to customize his map representation. With the plug-in he is able to use line width to indicate the amounts of bus passing by on different routes.

Although I summarize the map making process into 4 steps, not every participants perform all 4 steps to achieve their goals. For example, P9 and

P13 do not go through the pre-processing data process but directly extract data from their focus area and use it in SketchUp as the base for making 3D maps, while P6 do not need to polish his map for final representation.

4.6 Results

4.6.1 Object of Interest

In both QGIS and ArcGIS geographic data are presented in layers. I noticed that when participants described their interaction with in GIS software, their object in interest could vary from the whole layer to elements inside one layer.

Layer as object of interest

Layer is considered as object of interest in many interactions with the system. Two participants mentioned that they use layer as input for applying analysis method and generate new layer as output. When P5 was applying network analysis method to analyze transportation time, his result with different transportation tools was saved in different layers. Similarly, P6 searched for POIs that are close to national roads and saved his search result in a separate layer so that he could extract them out for further usage. P10 see layer as her input elements when she worked on site analysis for finding place to build a new hostel. In this task she needs to overlap multiple analysis result that are stored in different layers and give them different weight. These layers are then treated as input object when she was manipulating the weight. I also observed that layers are used as a way of managing input as well as output in multiple spatial analysis methods that professional users use.

On the other hand, layer is considered as object of interest when adjusting visualization. For example, P5 mentioned that he adjusted the sequence of layers to adjust the hierarchy of information displayed on the map. 7 out of 13 participants mentioned that they apply color or styles to layers for reasons such as grey out the less important information and for aesthetic reason as shown in Fig4.2 .

In both of the case, layer is considered as a object of interest to interact with a set of data at the same time.

Element in layer as object of interest

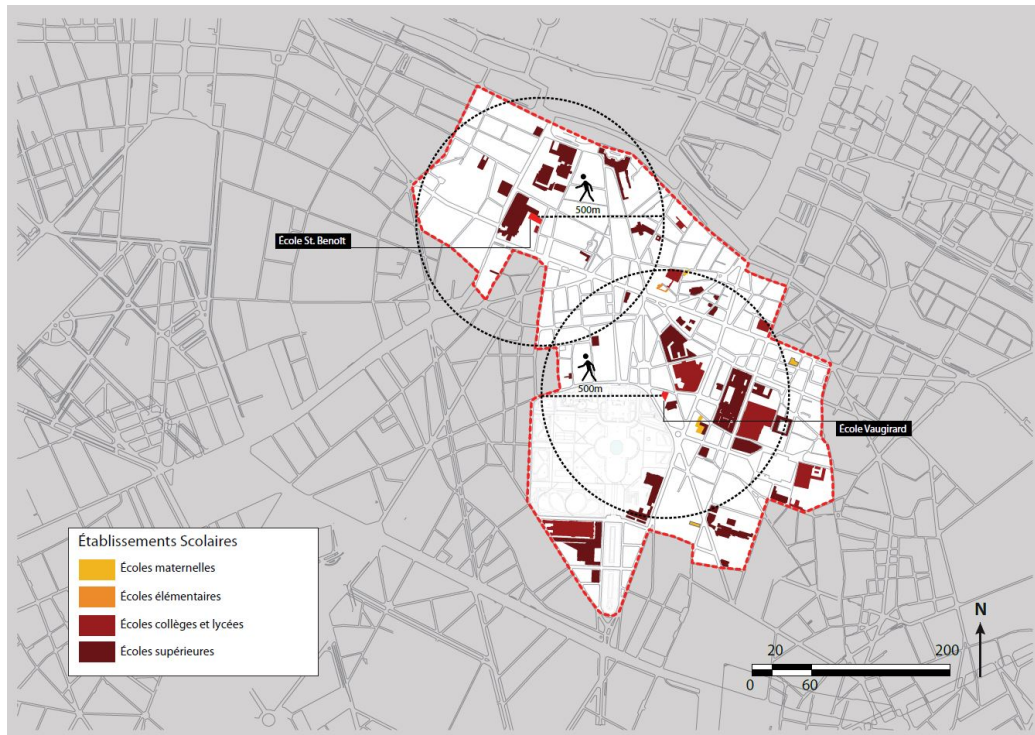


Figure 4.2: P9: grey out regions in his map

Participants also interact with elements within layers. For example, filtering data is one of the very frequent task performed by participants (9 out of 13). When setting up criteria for filtering data within a layer, they are focusing on the elements within the layer instead of the layer itself. Another example would be in the visualization process. 4 out of 13 participants mentioned that when they want to highlight some specific elements (one route or one point), they would give them colors that are different to other elements in the same layer.

4.6.2 Distance used as core analysis criteria

When looking at the tools participants used for analysis, I found similarity between several tools. For example, P5 used network analysis for analyzing transportation accessibility from transportation hub to city center of Tallinn. This tool works by first specifying a starting point, and then calculating transportation distance, or time, or any other kind of cost can be calculated based on the provided network. In the end P5 got a map with different zones

that people can reach within 15 and 30 minutes.

P10 used a similar tool for finding out places that are close to tourist attractions called Euclidean Distance. To use this tool, she need to specify where are those sightseeing places and the minimum meaningful distance to measure. She then get a heat-map style map, with distance to sightseeing places displayed in different color.

I also notice that there is another tool called Buffer Analysis¹. Professional users applies it to elements on map for finding out other type of elements that are within certain boundary around that element, such as finding POIs that are within 2km boundary of a road. With this tool users are able to create a area with determined distance around the original elements. Users overlap these buffer area with the layer that they are interested in and then can find the overlapped elements that are within the buffer area.

The three tools mentioned above are very similar to each other, as they are all analysis method based on the idea of calculating distance from one determined starting points. Network analysis and euclidean distance are two very similar tools: they both have to specify the starting point for calculating distance, and they both visualize distance on map.

There are only two differences between network analysis and euclidean distance. First is that they use different subject to calculate distance: euclidean distance use the direct distance between two points on map to calculate distance and network analysis use the pre-defined road network and value attached to roads for calculation, which is a more complicated but also more realistic way for calculating distance. Because the value attached can be modified by users, network analysis can also be expanded to calculate other attributes that are based on distance, such as transportation time or transportation cost. The other difference is the output they produced. Euclidean distance provide a more detailed raster map which show detailed information such as transitions between two distance. The output of network analysis, on the other hand, is a more abstracted raster map that only shows the region within pre-defined distance.

Buffer analysis is also based on the concept of distance. It draws a circle with the input element as central points and the defined distance as its diameter. When creating multiple buffer areas to a single POI, it can also

¹<http://desktop.arcgis.com/en/arcmap/10.3/tools/analysis-toolbox/buffer.htm>

create multiple zones to indicate different places that can be reached within certain amount of time or distance. This is similar to a combination of the network analysis and euclidean distance, but a less complicated and less accurate version of them, and therefore is used in QGIS for achieving similar result by GIS professionals.

There are some other tools that also include the concept of distance. For example, when P5 was working on another analysis on the density of buildings in city, he needed to cut the city into grids and calculate density based on the grids. When defining the size of the cell for cutting the map, it also involves the concept of distance. Distance can be seen as a core concept when map makers are interacting with their maps and analyze their data.

The fact that there are similarity in these provided tools also give me inspiration that I could search for similarity across different tools and try to unify them and make them available in a simpler way.

4.6.3 Customizing Visualization

Although there is a large set of default visualization effect provided in GIS, I noticed that participants still prefer to set up their own set of rules for presenting data.

When P1 was creating a thematic map, she created her own visualization of pie charts in Excel, and import these pie charts back to her Arc GIS project. Although there is already a default pie chart that she could directly apply in her system, she still preferred to developed her own visualization in Excel because *“the pie chart provided by Arc GIS is really ugly”* and *“I cannot find a way to adjust it/to achieve what I want”*. P5 designed and manually made his own tags, as shown in Fig4.4 for visualizing the multiple criteria he used for assessing the neighbourhood streets, because *“it is hard to show multiple kinds of data on a single map [at the same time in Arc GIS]”*.

P4 made his customized visualization with automated tools. He used a script to adjust the line width in his visualization to represent the frequency of buses passing by. He also mentioned that *“The tools for showing traffic size is one of the tools [that I frequently use], especially as I a working on transportation planning, I need to figure out the traffic size, but neither Arc GIS nor MapInfo has this function. [But]I know that there is another software specially designed for transportation planning have such function, that you can see the traffic size by selecting starting point and ending point.”*

P13 customize his own visualization by setting up his own color for different objects in his map. As shown in Fig4.3(a), he set the polygon for representing rivers to be blue, *“to make it easy to understand that this is river here”*, while the other map in Fig4.3 he change the polygon into green *“to show it’s green area here”*. In this map he also gave purple and yellow color to several buildings *“to indicate we are looking at these buildings”*. In his first map shown in 4.3(a), he also greyed out the zone that he isn’t focusing on to make it clear to his map viewers which part his focusing on. In addition, he also mentioned that *“So having nice map means having the right amount of elements so that it’s not too busy or too crowded. And, for example here I only used a few colors so that we can see it(my focusing area) here more easily.”* He customized his map visualization by limiting the amount of color he used, to make it easier to read.

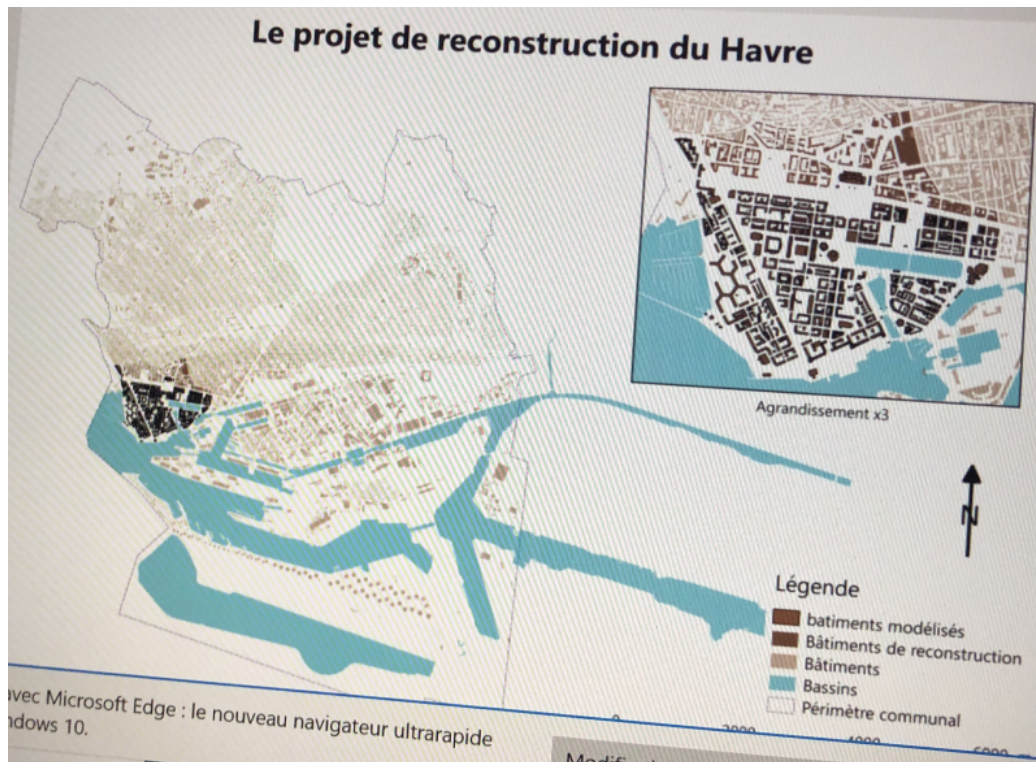
Additionally, I also noticed that P9 and P13 made a 3D Map for presenting their focusing area. The 3D map P13 made can be seen in Fig4.3. However, the 3D map they made do not support the analysis task but is purely for presentation. P13 also made an video for presenting the 3D map in SketchUp. They both consider making 3D Map as *“a more interactive way to present the project”*, because *“it can show the surrounded area and its environment, and this help viewers to understand what is the problem here”*(P9) and thus has its unique value compare to the map in 2D.

Customize visualization is the most frequent tasks that participants perform outside GIS for the two reasons: to present data clearer and with better look, and to express more information than the default visualization.

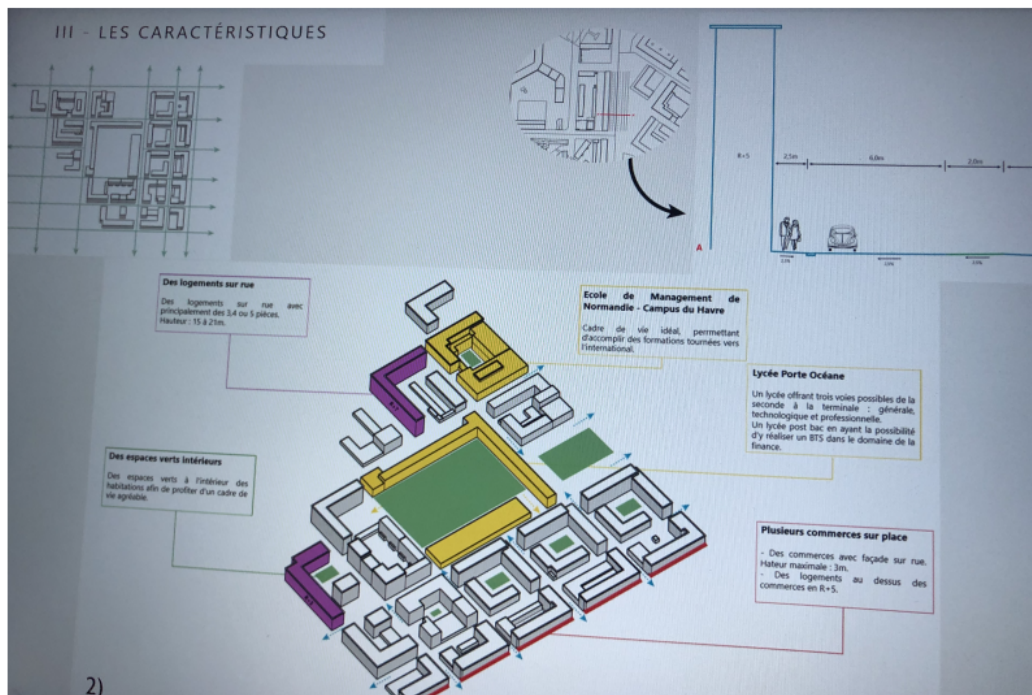
4.6.4 Learning curve

QGIS and ArcGIS are complicated system designed for professional users with more powerful features. It is easy to understand that these two software should be much harder to learn than Google Maps that is designed for novice users. However, participants still complain about ArcGIS and QGIS that they are too hard to use and not user friendly.

Some participants(3 out of 13) are still in their early career and have only started to learn and use QGIS or ArcGIS for less than a year, which is easy to understand that they would have problems with using them. For example, P6 started to use ArcGIS half a year ago. He complained that ArcGIS doesn’t show him a very clear error message when things went wrong,



a



b

Figure 4.3: Two maps made by P13: (a) A map to represent focus area, (b) A map for a residence area to show green lands between buildings

and thus make it hard for him to understand the current situation of the system and his task and how he should fix it. To understand the provided error message, he searched online and get different solutions. He tried one of the solution but *“it just worked for two weeks... and than it suddenly stopped working for no reason”* and he had to find another solution for the very same problem. He also complained that it is hard to understand how ArcGIS works. One example he gave is that when he was trying to export his filtered result from attribute form, he couldn’t export the filtered data out although *“there is a export button there”*. Instead, he needed to go back to the layers and click the layer he wanted to export. *“I feel like this is very stupid, why can’t I just export my data from attribute form?”*

Another early-career user, P11 mentioned that she had to be extremely careful when following the tutorial from her course. Although she said that she got a very detailed, step-to-step tutorial, she still needed to be very careful when following the steps. But still she has problems such as don’t know where the feature is and don’t know where goes wrong. *“I can’t really search anything in ArcGIS... there is a search bar ..., but I can’t really use it for searching for tools that I want, and I have to open every single menu to look for the tool that I want to use...like intersection(one tool)”* *“Sometimes I was stuck because I don’t know where the feature is, or where I put wrong parameters or forget to check some check-boxes... (mostly)minor details like these, if I didn’t pay attention I might make mistake...and if there is really just tiny differences between mine and the tutorial, I might not be able to notice that tiny error and keep going with that error, ended up with totally different final result(which I don’t want).”* When such novice users are exploring the system, they don’t get a clear understanding of what those parameter means, why do they need to take such steps, and how they could achieve their goals. The are mainly just following the tutorial without understanding.

Participants who already have experience with ArcGIS also mentioned that they don’t know how to use ArcGIS properly yet. For example, P1 has already worked with ArcGIS for more than four years, but still said she feels like *“there is too many features that I never used”*, and *“There are too many features and too many buttons in the interface, I always have to hover on buttons to see what they stands for... it is also hard to correspond the name of certain tools with their functions”* She gave positive comments that as her learn more about ArcGIS, mostly because she knew more about how powerful this tool is in modifying maps, but still, as this is a software designed for geographic specialists in all disciplines, she found a lot of buttons in the interface she never used and never get chance to understand.

Similarly, P5, who also have experience with ArcGIS for more than three years, gave the comments that he thinks there is too many features one could find and use in ArcGIS. *“I have to search for what tool that can achieve my goal and see how should I use the tool... there is many details that I need to take care of, because if you ignore some parameters or put them wrong, the thing you get out of that might be completely wrong and therefore you have to redo it. However, it normally took 3-4 hours to run the tool so it took me a lot of time in trying different tool and repeat the process to see whether it works... there are many different tools that can cut the objects, but there are only 1 2 tools that is really efficient on cutting the shape of architectures and separating them into different grids, and I had to try each of them to see which one works...whenever it fails it wasted a lot of time.”* There is a lot of features he never tried before, and as there are multiple tools that can achieve same effect, P5 spent in a lot of time in trying and error and thus considered it not very friendly for beginners.

Participants also find it hard to find out the correct tool to use because of the lack of tutorial and guidance. For example P5 searched for tools for the correct tool to find intersection points of two roads, P6 tried find a tool to find points that are within a polygon area. The reason behind their exploration of tool is also explained by participants: *“Arc GIS doesn’t provide a very good tutorial (for learning how these tools work)”*(P5), and *“I couldn’t find a tool in Arc GIS that support my requirement, although I think this should be a very frequent task and have to turn to use scripts (written by others) instead”*(P6).

Another interesting comments P5 gave is that he considers QGIS to be more user friendly than ArcGIS for the reason that QGIS has a clearer interface and less functions that beginners need to struggle with, but these provided functions *“is totally enough for beginners”*. However, he also mentioned that the QGIS provide less spatial analysis functions that he needs, and therefore he could only complete simple analysis in plain 2D in QGIS. The fact that QGIS has less spatial analysis functions made him mainly analyze his data in ArcGIS, and turn into QGIS for adjusting map visualization.

One of my participants is an expert in ArcGIS with experience over 10 years, and for him *“There is no problem for me in using ArcGIS”*. When talked about other alternatives for geovisualization, this expert user considered that *“I can do anything I want in ArcGIS...but it doesn’t give me that level of control and good quality of visualization in the other options (D3.js and other python libraries)...”*. He also said *“it is hard to make us (who work*

with geography) to switch to those libraries...although I know they have better visualization effect, but most of these I can do in ArcGIS and I don't want to learn them again(in the new platform)".

Participants experience with learning ArcGIS has shown that it is hard to be an expert in ArcGIS, as it is an extremely complicated software and there is lack of supports in tutorial. The fact that it is hard to learn also makes it hard for expert users to utilize this powerful tool. This inspire me that when designing for a new tool for geographic specialists, I should build a tool with clean and simple interface, and try to unify the tools that seems to be similar to users.

Direct manipulation Seven participants who work with Graphical editing software in their projects such as Adobe Photoshop and Adobe Illustrator prefer them to ARcGIS and QGIS. When asking why they prefer Photoshop or Illustrator than ArcGIS and QGIS, most of them answered very vaguely such as *"I don't know, I just feel like Illustrator/ Photoshop is designed more user-friendly and has a better designed interface."*(P4,P9) When looking at the tasks they perform in Photoshop and Illustrator, I noticed that they mostly modify objects color(7/7), add new object to the map(3/7), add legends and title(4/7) in Photoshop and Illustrator.

In their description I understand that they enjoy adjusting color in Illustrator because they can directly select the object that they want to change color, and change their color after selecting them. With the ability to directly manipulate object attributes or shape, it is much easier to adjust visualization than doing so in QGIS or ArcGIS.

A lot of limitation for adding legends exist in ArcGIS and QGIS. *"I can only create legends in one row or one line, but I want my legends to be like this(in 3*3)"*(P5)(Fig 4.4), *"When scaling up my legends, ArcGIS automatically adjust its layout for me, but I do want it to be kept in 2*2 instead of 1*4 (that ArcGIS automated adjusted for me)"*(P1), *"even though you can add legends in QGIS, I found out that that is not very nice, it is a little hard to manage, and [in] Illustrator is a lot easier."*(P9). I found out that the preference for editing legends and title in Photoshop and Illustrator is because of the freedom to adjust its position and its layout.

Three participants also mentioned that they would like to add new elements onto the map in Illustrator because of the fact that they have freedom to create their own visualization for the new element and they can directly

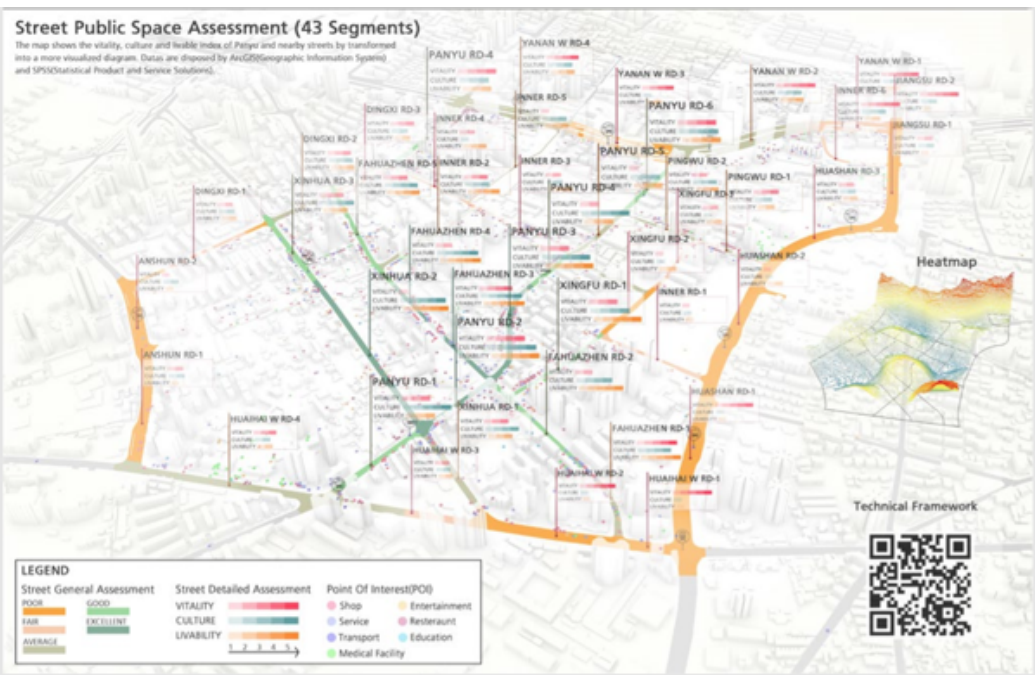


Figure 4.4: P5: map for street public space assessment

move them to desired position, which is hard or no way to achieve in ArcGIS.

In general, participants prefer to interact with their objects on map with direct manipulation such as dragging and dropping, instead of the sets of pop-up windows style provided by ArcGIS and QGIS.

4.6.5 Visualization for understanding data

Six participants explained that visualizing data on map is a way to help them understand data.

“I put my data into ArcGIS after my data were processed in python or after I get the result that I want... for example when working with my air pollution project, I visualized my data after every step I processed my data to see.”(P1)

“I’m gonna to reflect the changes of social and economic data of Xuchang and Zhengzhou onto the map, to see which area has the most rapid change and then choose it as my research area...”(P3)

“I also need to calculate the empty rate of each train and after processing these data, I imported them into MapInfo (to view them)... I can see how many trains passing by in a certain area and what kinds of trains they are, and

therefore understand the balance of trains coming and going in that area (by just viewing my map)” (P4)

“Now that we can easily get access to many different kinds of data (and use them to analyze and find problems) to support our design decision-making process in a more scientific way.” (P5)

“I can see and understand where has more taxi coming in, where is more frequently set as destination, where most passengers are going from and to (by visualizing the track of taxis)” (P7)

Participants put their data into map for viewing data processing result, reflecting and understanding problems, and finding patterns. I also asked why they have such preference of visualizing their data in GIS:

“If I view data directly (in text), it is hard for me to see how they are distributed.” (P1),

“It is hard to see actual relationships by viewing the table of data, on map these areas are connected geologically, so I can see whether certain element or phenomenon is expanding or narrowing down, or that industry developed here would transfer to nearby cities.” (P3),

“In this way these 1200+ lines and 10+ rows of data can be shown with a short glimpse on the map. I think it is a more direct way for communication, and it looks also nicer. I can also make a bar chart in Excel (to achieve my goal), but I feel like when I put these data on top of map, I can show the position of the cities and the amount of train stops (at the same time), and in this way it is more direct and you can get more information (than just showing a bar chart), and these information are easier to accept by human brains.” (P4)

Participants take the benefit of their data are geological connected and use it as the key feature to support their exploration of the map and their own data set. Visualizing such data onto map helps them to reflect and see patterns and problems on map, and help them in further decision making process such as what area they should look further into, how they should process their data and how they should make design for solving the problem. It is noticeable that they are not only making visualization for presenting the data to viewers, but also as a tool that they use for observing and analyzing their data. Also, in most of the cases they don't have a clear idea on what area they will be focusing on or what problems will be presented on the map. They figure out these focusing area and focusing problems by visualizing data on maps. Visualizing these geographic data onto map is the powerful tool that they use for understanding not only the data itself, but also different areas on the map and problems hidden under the pattern.

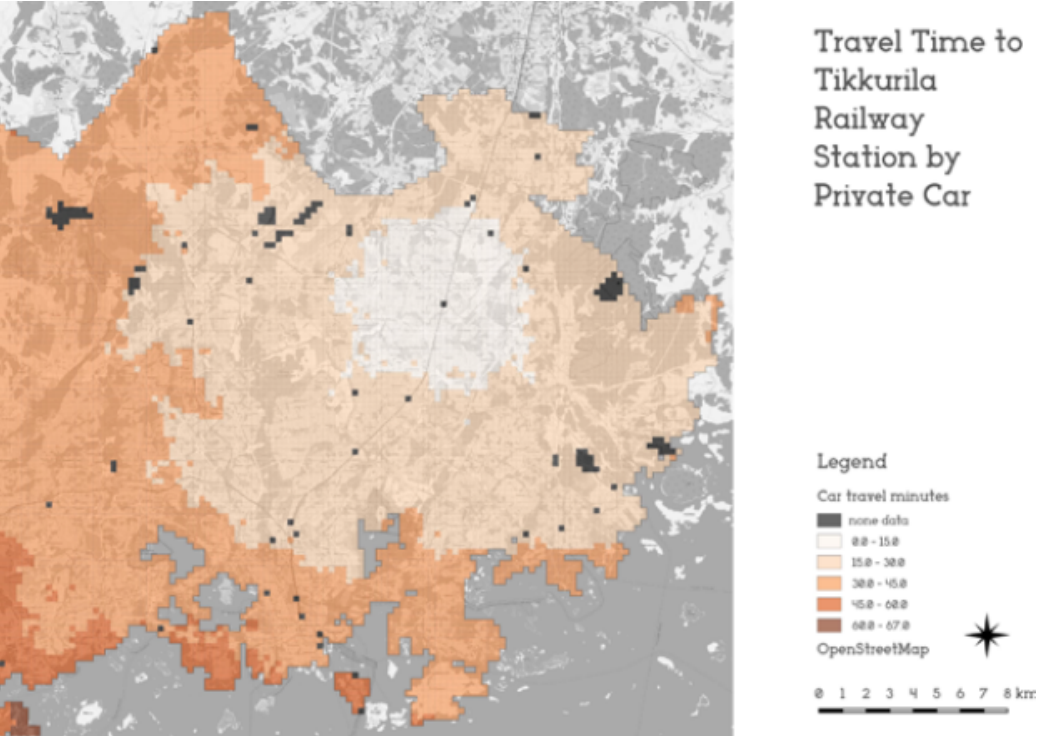
4.6.6 Overlapping strategy in visualization and analysis

Participants are mostly focusing on making thematic map (11/13) instead of reference map. The map that they make are mostly under the structure of base map +analyzed data. Analyzed data are presented in one or multiple raster or vector layer. By base map, participants refers to the map with basic topographic data, such boundaries of political districts, rivers and roads information. After analyzing data, participants would overlap these information on top of a base map, to help map viewers understand the context and familiarize them with the map.

By base map participants refers to map with basic topographic information. These base maps are typically created by other institutes and have a standard information conveyed in them: topographic boundaries, roads and buildings. The two most common sources for base map is either shared by others within their institute, or open-sourced data and online maps. For example, P4 used base map shared within his company, P5 used base map from Google Maps and OpenStreetMaps as shown in Fig4.5, and P9 used a open-sourced base map he found from a French institute's website.

However, although most of them add base map in their map, it doesn't help map makers much with the analysis and decision-making process, but rather only serve as a background for helping map viewers to understand the map. P4 also gave comments like *"Base map is the least interesting and least useful part in my map, but I still need to have them to help people to understand my map."* Thus, mostly map makers only request base map to help showing the topographic information without further requirement, and therefore would turn to use the base map that they can easily get access to. They use overlapping base map as a strategy of visualization, to help map viewers quickly understand the information shown on map. P4 gave an example: *"Most of our clients are people like a mayor, who might hang a map in his office, and if you show your result on the map, and pointing the map in front of the client that there is problem in transportation between here and there, it is much easier for him to understand, because he sees the map every day and he knows the city well."* Topographic map can help map views quickly locate where they are looking at on the map.

Overlapping is also served as a technique for data analysis. When performing analysis task, participants require data that are stored in different places and put them together in GIS. For example, P1 and P3 used GDP data collected online to reflect economic changes on map, while P4 used data of train



a



b

Figure 4.5: Two maps using different base map provide by P5: (a) Using Google Maps as base map; (b) Using OpenStreetMaps as base map

schedules and passenger flow on each train, and P12 used the literature on how a famous person have moved has the source of her data. Participants use very different data set for their analysis task.

In some of their analysis task, participants need to use multiple criteria for assessment. For example, when P5 was making a map for assessing neighbourhood as shown in 4.4, he used 3 different criteria for assessment: street vitality, culture and livability. These 3 criteria are assessed by activities being held, habitability, facilitates as where as cultural spots in the regions. He accessed these criteria one by one, and then overlapped these criteria too get a general assessment of the region.

Another example would be P4's project. P4 was working on redesigning part of transportation routes in the city. He put lines to show how many trains passing by on the railways, and also put a pie chart to show how many train stops there. By overlapping the traffic size and how many trains stopped their, he can see how is the balance of trains coming and going in the area. With these two information visualized on map, he could know where he could add more trains stopping at one stop.

Participants do not only overlap their vector data, but also overlap raster data and combine them as a multi-criteria analysis. For example, when P10 was doing site analysis for finding place to build a retort around the tourist area, she needed to find a place with suitable slope, close enough to the touristic area as well as to the roads. She created 3 different layers to represent slope, distance to different kinds of POIs and combined them together by specifying a weight to each criteria and combine them to generate a new map as the general assessment.

4.6.7 Exploration and repeated work

Participants explored a lot while performing their tasks.

One kind of exploration can be easily seen is that they explore on the maps to find problems, patterns and area they should be focusing on. For example, P3 used map to find her research area with abnormal economic growth patterns. This is because that one of their purpose of making map is for exploration to find patterns and problems.

The other type of exploration I notice is that sometimes GIS professionals need to explore the correct parameters. When P10 was doing the site analysis for the retort, she needed to explore and setup weight for each criteria,

the maximum slope angle and how distance are calculated by herself. *“as the weight is actually decided by us, there might be multiple way of giving weight to these parameters, so we have to discussed a lot on deciding the weight. Sometimes the result of possible land after giving all these weighting and filtering, the (result land) size is not big enough, because in the calculated result the lands are split into tiny pieces. Some places were cut off from the presented result because of its slope didn’t meet with our requirements, but actually their slope wasn’t that large that it totally won’t work as we could also flatten that part in the construction. However, since it was cut off from the area, that land was cut into pieces and the overall size of the area wasn’t large enough and therefore this whole area was filtered out from the map. When these area are all filtered out, we didn’t find any suitable area (for building the resort)... and we need to go back and reset all the parameters”*

Although P3 has mentioned she did such kind of weighting and filtering result based on statistics principles, it cannot be applied to P10’s case. For P10, there isn’t a strict rule that she should be looking for land that are surely with certain slope, or distance to the touristic area that are certainly within 2 km, there isn’t a setup rule for her to follow. For her, she only had a very vague idea that the resort she was looking for should be in a relatively flat place, and should be as close to touristic area and roads as possible. However, the setup weight affects the end result she perceived and she had to try to figure out the best combination of each parameter she would need.

A lot of repeated work are accompanied with explorations. For the exploration of parameter, P10 needed to go back to test different combination of parameters for several times. P10 also mentioned that she spent a lot of time in this exploration process, going back and forward, testing and repeating similar tasks.

Another type of repeated work is not because of exploration but the modification of analysis elements or parameters. For example, when P5 was making the transportation analysis map, he needed to repeat the work of creating map for 3 different types of road. For him the only thing changed is the data set of road he used, but he need to apply the same analysis method, with similar parameters to every single type of road and thus repeat the work of manually setting up parameters and apply them to the roads for three times. P5 also faced repeated work when customizing his visualization in 4.4. He manually made every single tag on the map in Photoshop and had to repeat the task of creating customized tags for every single tag. Similarity, P1 also mentioned that she manually created pie charts for better

visualization result in Excel and imported them back to Arc GIS.

The third type of repeated work is not connected with exploration, but finding the correct tool to use. For example, P5 needed to repeat the process of trying different tools to find out the tool that worked for his task for 3-4 times.

It is noticeable that some of the tasks themselves leads to repetition tasks for GIS professional, while they are time-consuming and remained almost the same, current GIS does not support GIS professionals to avoid such repetition.

In summary, there are three main problems that users have with GIS:

1. Lack of support for exploration: users need to explore during the task to figure out their focusing area or focusing problem, to find out the tool that supports their tasks, to find out the parameters that help them to achieve their goals. These leads to repeated work performed by users.
2. Lack of support for customizing visualization: users are unable to control the visualization and the graphical representation in GIS and therefore need to use other tools and software to achieve their goals.
3. Hard to learn: Because GIS has complicated interface and a large volume of its tool sets. For novice and intermediate GIS users they need to spent a lot of time in understanding tools provided.

Professional map makers perform two strategies when they are exploring in GIS:

1. Visualizing data: they visualize data onto map to understand their data and also to get feedback on their data-processing process.
2. Overlapping: They overlap multiple layers for analysis in their tasks.

Also, there are two common patterns professionals perform while interacting with GIS:

1. Distance as core criteria: They use distance as core criteria for conducting analysis.
2. Object of interest: Their object of interest switch between layers and elements within layers depending on their task and tool they use.

Chapter 5

Designing for GIS Professionals

In this chapter, I describe the design goals I extracted from my result and from the design guideline of instrumental interactions[4, 5], the design scenario that I used for designing the tool, and three iterations of my own design concept.

5.1 Design goals

I extracted design goals from the result of my interview study and based on the concept of reification, reuse and polymorphism from instrumental interactions[4, 5] for providing guidelines when designing solutions for GIS professionals. After that, I present three design alternatives that I explored in the design space: Mask, Bubble, and Buffer Region. After each design evaluated two of the design alternatives by making video prototypes and going through the video prototypes, and use these feedback for iterating my design concept.

5.1.1 Direct manipulation

Map makers show their preference to graphical editing tool as they can interact with their map by clicking and selecting the object of interest. Compare to the interaction provided in GIS by setting up parameters in pop-up windows, they consider this to be a easy to understand and efficient way as the tools are easier to find and apply to objects. They prefer to have access to manipulate their data directly by clicking and selecting the object of interest. Support for more direct interaction could also help map makers in spending less time in searching for tools in the interface. When designing new tools

for map makers, there should be more support for interaction by clicking and dragging, and less pop-up windows style interaction.

One example that direct manipulation could solve is that for P3, she preferred to create new POIs in Illustrator, because “*I can put it at any place I want*”, and also it is hard to specify a point in GIS as users need to give the exact location of that point. Direct manipulation could also help with solving the problem of adjusting color while customize visualization. In GIS it is hard to adjust color as users have to set up a lot of parameters and go through multiple steps. Therefore, P5, P9, P4 and P10 have chosen to adjust colors in Photoshop or Illustrator for adjusting colors. If the same task can also be achieved by simple selection in GIS, it will reduce users task of going to graphical editing tool. They also have the problem that the edited map cannot be put back to GIS, and this means that if they have to adjust in the original map, it will lead to the result that they have to redo everything in graphical editing software.

5.1.2 Support for exploration and avoid repeating tasks

Map makers explore a lot when they are making their maps. They explore their data to find patterns and relationships hidden behind the pattern. They also explore for the best tool as well as the best parameters they should use to get analysis result that they want. However, exploring parameters leads to repeated works that map makers unwilling to do. Also, map makers have to remember the parameters they used before and manually type them to the input box every time when they were repeating the step and this increase their mental efforts for their explorations and repetitions. Therefore, helping them with the exploration and eliminate the repeated work during their exploration would be a possible design direction for supporting professional map makers.

By supporting exploration it can help repeated work such as repeating applying analysis methods and generating maps to find the best parameters for weighted overlay in the use scenario provided by P10.

5.1.3 Allow going back and forward

Map makers often redo some of their analysis process to seek for the best parameter for analysis. However, the current system does not support reminding them the parameters that they already use and only show them the

processed image as the final result, map makers lose the parameters after they set up and apply the analysis method. Therefore, they have to remember what parameters they used and thus decide what they should use next based on their own records or memories. For example, P10 need to remember manually the combination of parameters she tried for searching for the best parameters for applying weighted overlay. The new tool should try to support this exploration process by allowing users to go back from the processing result to view the parameters that they applied.

5.1.4 Easy to find and reach tools

Many map makers complained that they found the interface of ArcGIS is complicated and hard to understand, because there are too many features clustered in the interface. The clustered interface also bring them trouble in finding the tool that they want to use because they are hidden under some menu bars. The new design of the interface should make the tool easy to reach and understand. This could supports P1, P5, and P10's problem of hard to find out tools they want to use in ArcGIS's interface.

5.1.5 Easy to use for early career users

Although ArcGIS is a very powerful system designed for geovisualization, participants has shown us it is hard to truly understand and utilize this powerful tool. I want to include more supports to novice and intermediate users, and even make it applicable for daily geographic information searching tasks. I want to make these analysis methods better support professional use with less struggling with the learning process. Also, these powerful tools used by the professional can be applied for daily tasks, for example when searching for a nearby restaurant in several alternative regions. If they are easy to use for beginners, it might also be able to be applied to such searching tasks for online map users. Therefore, I want to seek for a tool that is easy to be used and understand for beginners as well.

5.1.6 Support for reification, reuse, and polymorphism

Reification means to reify commands or tools that users can interact with, reuse means that created objects, or the process of creating project can be

reused on other objects, and polymorphism means that one tool can be applied on different types of objects[4, 5].

I notice that map makers are always creating their own setup for visualization as well as analysis methods. For visualization set of rules, they create their own set of colors, own symbol, or own rules on length/width/color gradients for representing data. For analysis methods, the majority of analysis methods requires them to specify a series of parameters, which can also be considered as a kind of own set of rules for manipulating data. These setup rules are repeating being applied different object during one project. Reifying the analysis methods, or the rules for visualization could support their preference of direct manipulation, as they are turning to be an object that users could interact with. For example, when P5 was making his own tag in Fig4.4, he had to manually apply it to every data he get for making the visualization. If these preset relationship between visualization and data is reified, he will not need to manually make every single tag because he could directly manipulate and define how the value would change visualization.

With the design principle of polymorphism, it could help creating a simplified and easy to understand interface. As there is similarity in map makers applying analysis methods or visualization rules to object of interest and there is also similarity in analysis methods map makers use, it would simplify the interface if these analysis methods and visualization rules can be unified onto a same object or conducted by a unified tool.

Also, the design guideline of polymorphism could help with reducing repeated tasks. As map makers sometimes need to apply same analysis method or visualization rules to multiple objects, creating a group of these objects and applying analysis methods and visualization rules to the group could help reduce the repeated task performed by users.

Reuse could provide support in reducing repeated works. As users needs to apply the same or similar analysis methods or visualization rules to different object of interests, reusing the input of setup parameters or setup visualization rules could help users in reducing their work when applying one analysis method to multiple layers. For example, the reuse of parameters can help P5 in eliminate his work when generating separate transportation accessibility map for different type of transportation tools as shown in Fig A.1.

5.2 Design scenario

As problems I collected from interview study can all be found on my participants who are urban planners, and they also perform the two patterns I discovered and use the two strategies I found in their tasks, urban planners is a reasonable option of the user group that I design for. I also notice that different types of GIS professionals conduct different tasks, for example, P6 as a data scientist may focusing only on data processing, and ignore some other tasks such as visualizing data and polishing map, while 4 participants in urban planning (also including 1 in transportation planning) provided their use cases that have went through all 4 steps of map making. Therefore, I decided to focus on the user scenario provided by urban planners.

Among the user scenario, I found out the scenario provided by P5 and P10 of locating new retort and designing a city with better transportation accessibility are most inspiring. These two scenarios are both very typical tasks for urban planners, and they are complicated enough and therefore involve the entire procedure of map making I summarized from my interview and problems I found in my study. Also, in both of the scenario, they involve multiple data sources and multiple analysis methods for a design project in a large scale, which can nicely represents what are the tasks would like for urban planners nowadays.

For the user scenario of finding place of building new retort, the goal of user is to find one, or a few optional places for building new retort on the map. The requirement of the new place could be that the place itself should be large enough while the slope is within certain boundaries so people can build architecture on it, and it is close to transportation hub while shouldn't be close to other touristic area. To finish this task, urban planners need to first start with collecting data such as Digital Elevation Model(DEM) of determined area, land use and POIs within the area. For pre-processing data, user need to filter out POIs such as bus stops and touristic area among the collected POIs and find out area that can be used for building retort depending on land use. After that, users need to perform slope analysis with DEM for finding out area with proper slope angle, euclidean distance analysis for exploring distance to different POIs, and finally weighted overlay for combining these criteria. After finding out the optional places, user would take this map to graphical editing software for further polishing the map to present it to their customer. Throughout this process, user face multiple problems: they need to explore parameters of weighted overlay so that they can get an

area that is large enough and meets other requirements they setup, they need to customize their map, adjusting color and symbol and add topological information so the map is visually easy to understand by others, users need to use multiple tools, which might be a complicated task for early-career users.

For the user scenario of redesigning city based on transportation accessibility, the goal for users is to find out how to redesign the roads in cities so that it is easier for citizens to reach transportation hub such as airport and train stop within 30 minutes using public transportation. Similar to previous task, urban planner start with collecting data such as bus routes, roads in the city and topographic map of the city. Users then need to pre-process data to first separate type of roads into walking roads, roads for cars and roads for buses. After that, they need to perform network analysis for each type of road to get the boundary of where citizens could reach within 15 and 30 minutes. Based on the accessibility boundary, they analyze and explore how to adjust the roads to expand transportation accessibility. Urban planners also need to customize the visualization, such as giving new colors to the map and removing elements on map to make it easier to understand. As part of the outcome, users produce a series of maps showing transportation accessibility with different tools and with different design of roads. In this process, users need to repeat the task of applying similar analysis methods to different data set, and later on explore on editing the data set to get a new design of the roads. Although users are only using network analysis for analyzing data, there are actually multiple complicated steps for them to setup the data set for conducting network analysis. Also, in this scenario, users face the challenge of customizing visualization for a series of map, meaning that they need to apply similar visualization rules to multiple maps.

5.3 First iteration: Mask

My first design is inspired by the mask tool that can be found in graphical design tools such as Adobe Photoshop and Figma¹. Mask is a special kind of layer that convey a shape that can be used as a filter for displaying only part of the image underneath the mask. As shown in Fig5.1, when adjusting the shape of the mask, the shape of the displayed image can be changed accordingly. In Fig5.1 (a) the mask is in rectangle shape, it can shift to Fig5.1(b) by editing the mask, without damaging the image itself. With the use of mask, users can change the shape of displayed image underneath without

¹<https://www.figma.com/>

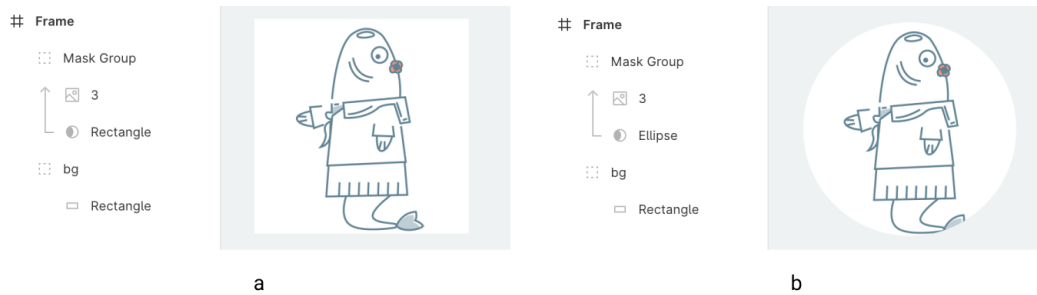


Figure 5.1: Mask in Figma: (a) image with rectangle mask, (b) image with circle mask

losing the ability to edit the displayed shape.

Mask supports the design goal of supporting user requirements of going back and forward between steps for exploration. Mask is a special kind of layer that records the shape that users want the covered image to be in. Users are free to edit the cover shape and the underneath image keeps as the same, so that users can make nondestructive changes to the image underneath by editing the mask. For the tasks of urban planners, the concept of mask can supports users need for redoing and undoing tasks for exploration, as it protects the original data and therefore easier for them to adjust changes on their needs.

With mask, the object of interest that I am focusing on is layer, which can be considered as a substrate of a set of data because users are frequently interacting with layers, by applying the analysis methods to layers or changing color or style of the whole layer.

Mask in GIS is similar to the mask in graphical editing tool. It is a special kind of layer that conveys the set of rules that users applied to the layer. When using an analysis method, users are attaching mask to the selected layer. A layer of mask can not only store one applied analysis method, but also multiple analysis methods. When multiple analysis methods is attached to one layer, users can drag to manipulate their sequence, and delete one of the analysis methods attached. By clicking at the mask that applied to the layer, user can see the parameters that they've set up and directly modify them for the purpose of exploration the correct parameters for analysis. Once the mask is set up, users are also able to reuse the mask to other objects by copy and paste it to another layer or by drag and drop the mask to a new

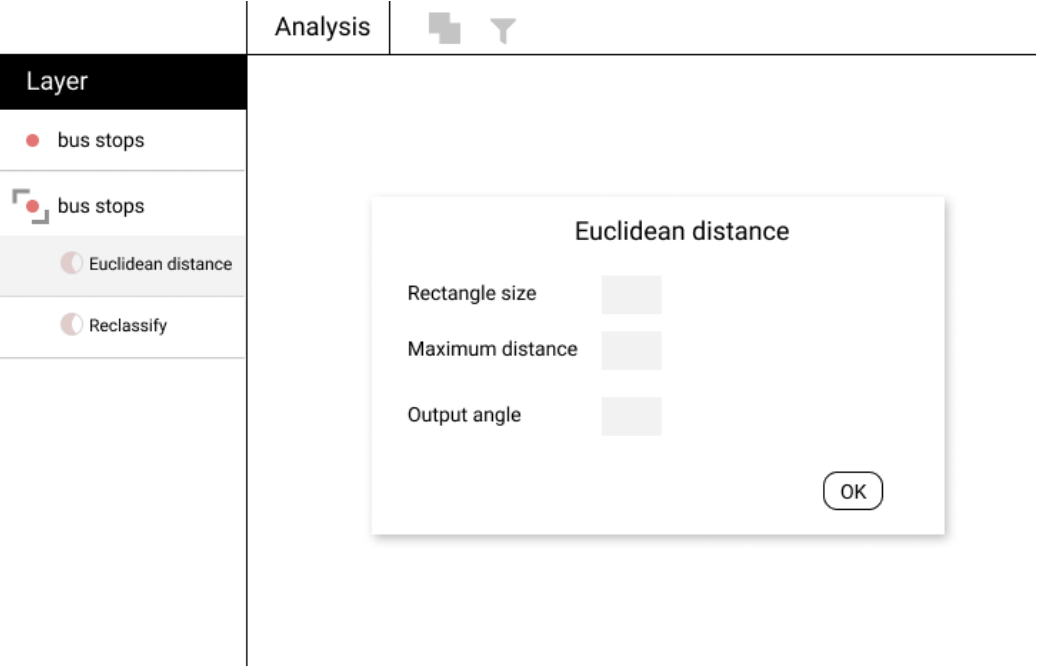


Figure 5.2: Design concept: the interface with the concept of Mask, with mask displayed at the left in layer panel

layer. Because mask reified the analysis methods and the setup parameters, users are able to reuse these mask to other layers and therefore reduce the repeated work of setting up parameters.

The mask could also support data processing process such as filtering data, which is similar to the original mask idea in graphical editing system. Users can either draw a boundary or setup a set of filter criteria to control what information will be shown on the map. For example, in the user scenario of finding new place for building retort, users could edit the boundary to expand the focusing area if the requirements are changed or if they struggled to get result from the current area.

Masks can be also used as a tool for customizing visualization. Users can use mask for changing color, and import symbol created elsewhere to represent the data. Similar to applying analysis method, users edit the color, the style, or add a symbol in the mask panel. The mask with visualization rules can also be applied to other layers by copy and paste or drag and drop. Also, one mask can have both analysis methods and visualization customization at the same time. With the support of customizing visualization, it could

better help users when they are setting up similar rules for multiple layers or for multiple maps as they can easily reuse the setup instead of creating them separately for each layer and for each map.

In order to offer a quick overview of what kind of analysis methods or visualization in the layer panel, the mask layer is designed to be able to show every single method/visualization that have been added to the mask. As shown in Fig5.2, in every mask layer, the layer name is setup to be the name of applied analysis method.

Mask also support for users to go back to view the original data. As shown in Fig 5.2, there are two type of layer logo, one is with a grey brackets, and one without. By double clicking the layer with grey brackets, users will be able to be redirect to the layer that store the original data and get access to the original data.

Different kinds of tools for interacting with map, including filtering, data analysis and visualization could be unified into one form with mask and therefore represented in a clear and easy to follow way on user interface. By unifying multiple tools with the concept of mask, the user interface could look simpler than the original design, also making early-career users easier to understand how different methods work in GIS.

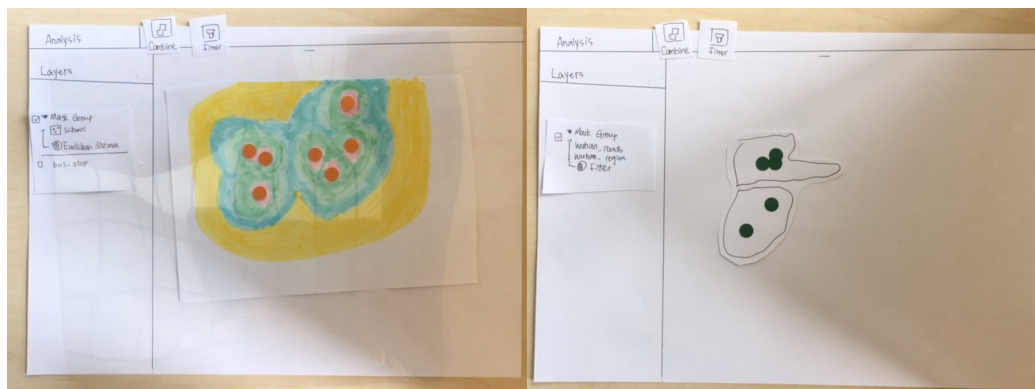


Figure 5.3: Video prototype for the mask concept

After developed the design concept, I made a video prototype as shown in Fig5.3 using VideoClipper² and reviewed the video prototype with few beginner users of GIS who have experience in design. According to their

²<https://ex-situ.lri.fr/projects/videoclipper>

feedback and my own review, I found the following drawback of the idea:

When there are multiple analysis methods applied to the same layer, it creates a long list of masks, and also multiple layers representing result of each step. This long list of masks is hard for users to navigate themselves between the layers and analysis methods they apply to layers.

Also, mask would work better if there is only one rule at a time attached to a layer as it will take time for users to see the change of result, because it takes time to complete rendering result for a single analysis result. However, when users apply multiple analysis methods, they cannot be changed independently. Changing the parameters in one intermediate step will certainly take a long time for user to see the changed result. When putting the idea back to the scenario of building new retort, I found that when they are analyzing data, they mostly apply more than one analysis method to the layer. For example, when finding the land that are close to the touristic areas, users need to first calculate the euclidean distance and then reclassify the distance value because the smaller distance value it is, the better it is in the criteria system, and also that they need to be unified to a scope so that it wouldn't bring problems when overlapping with other criteria for the final result.

The third reason is because that that mask is hard to be reused across layers in some cases. For example, in the provided design scenario of building new retort, user would need to reclassify the value for each of the criteria used. However, as different criteria would have totally different value scale, for example the value for slope would be totally different from the distance ones, user still need to manually setup numbers again. Although user has reuse the reclassify mask, it still requires user to edit the parameters, which make it not much different from selecting the tool again from the menu and set up parameters from the very beginning.

Last but not least, it does not fit when one analysis method requires multiple layers as input. It will be hard, to redirect users back to the original layer if there is multiple layers as input because the system will have no idea on which one it should redirect to. Also, when there is multiple layers as input, it is hard to indicate which layer the mask should be attached to.

In summary, although the design concept of mask seems to be a good way to provide unified interaction with layers while making maps, it is hard to manipulate for users when applying multiple masks to one layer and doesn't reduce the work of setting up parameters when reusing masks, and does not

fit with some of the analysis methods. Therefore, I decided to iterate my design concept and focusing more on reusing analysis methods and reducing the work of setting up parameters.

5.4 Second Iteration: Bubble

My second design concept is inspired by the concept of history in graphical editing tools. In graphical editing tools such as Photoshop, there is a panel called “History” that stores the history records of steps user performed in the system. In each records presented at the history panel, the system records the action users take and parameters of the action. Another example would be the recording actions feature in Photoshop, with which users could record the tool they used or the action they took, and the parameter of that action, for example moving left for 5 px, and can be reused to other objects for reducing repeating jobs. Instead of layers or elements in layers, I focus on parameters of analysis methods applied to a layer, which is not sustained in GIS and therefore cannot be manipulated or reused by users.

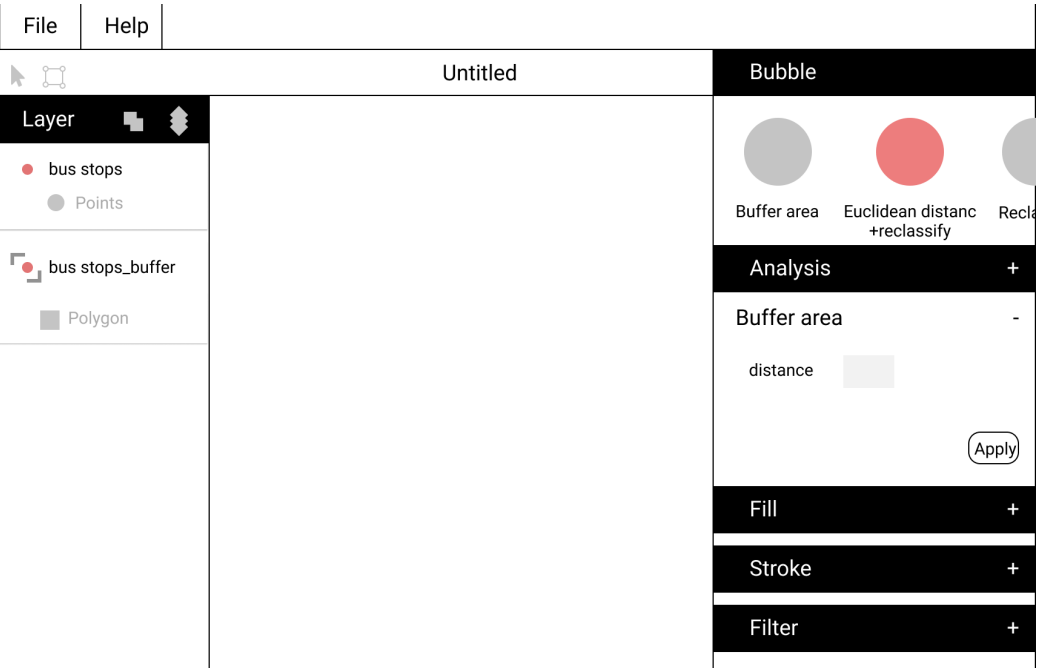


Figure 5.4: Design concept: interface with the concept Bubble, with Bubbles at the top-left Bubble panel

In this concept, bubble is a container for the set-up parameters for analysis methods. When using analysis methods in GIS, users need to setup parameters to determine how they will affect the applied layer. However, these set-up parameters are not sustained as they are gone in the system after applied. To reuse the set-up parameters, users have to recall them and also reissue them to other objects manually. In the concept of bubble, these applied parameters are stored in separate bubbles with the name of analysis methods. Bubbles enable users to interact with history parameters they used and utilize them for support of exploration and reduce repeated jobs. By clicking at a bubble, users could see what are the parameters they used for issuing that parameters. Users could reuse the bubble for applying similar analysis bubbles to different layer by dragging them onto the layer. Similar to the mask concept, bubbles are attached to a layer, but are not presented on the layer panel. Instead, the attached bubble will be presented in a separate panel on the right when clicking at the layer. Bubble can be combined with other bubbles by drag-and-drop to form a larger bubbles with multiple analysis methods.

Bubble could support users task of exploration as users do not need to manually remember the parameters they used when exploring parameters. For example in the user scenario of finding a place of building a retort, users might need to explore what are the reasonable parameters for categorizing distance from touristic areas. With the use of bubbles, users do not need to manually explore parameters, but just simply change the parameters recorded in the bubble.

Bubble supports reuse of analysis methods. In the user scenario of applying similar analysis methods to multiple layers for making multiple maps, users could simply drag this created bubble to multiple layers instead of making one for each layer.

Different to the previous mask concepts, users do not need to apply analysis methods by defining a bubble first. Instead, users can apply analysis methods as how they are currently doing in GIS: by clicking and searching the analysis method that they want to use. The bubble will be generated after an analysis method has been applied. When using the bubbles, users can find the bubbles that are automatically stored in the bubble panel on the right. Users could combine bubbles or edit parameters stored in bubbles and then apply the bubble to another layer of data.

To better navigate users between layers, in the interface of Bubble it does

not present any descriptions of analysis methods applied or bubbles applied on the layers. However, the applied analysis methods can be found by clicking at the layer, and it will be shown in detail at the Analysis panel on the right. Similar to the previous idea, users could also double click for going back to the original layer. What is different from the previous idea is that it won't generate one layer for every single method applied, but would only generate a new layer when raster data is converted to vector data, or when vector data is converted to raster data.

When designing the interface, I noticed that there is differences within the methods that users apply for analysis. Most of the analysis methods, such as network analysis and euclidean distance analysis only require one layer as input. When manipulating the relationship between layers, such as combine, intersect, subtract or exclude, it requires only two layers as input, with the exception that combine can be applied to more than two layers. However, there is also some analysis methods that related to overlay or summing up that can ask for more than two layers of data as their input. The bubble could be a good support for single-input analysis, but will be hard to determine which layer it could be applied to when there is multiple input layers. I found four types of analysis methods that requires multiple layers as input: fuzzy membership, fuzzy overlay, weighted overlay and weighted sum. To better support analysis methods, I separate the analysis methods into three kinds: analysis methods that only require one layer as input, relationship between layers that requires two layers as input, and analysis method that require multiple layers as input.

I separated these three different type of analysis methods by putting them into different places in the interface as shown in Fig 5.4. The single input analysis methods are in the analysis panel that is on the right. The buttons for manipulating layer relationships and for summing and overlay is at the top of the layer panel, and will be shown only if multiple layers are selected.

Also, different from the single-input analysis methods, these multi-input analysis method would not be stored in a bubble in the bubble panel, but will create a group with the selected layers. For the summing up and overlay methods, it will bring a input box in front of the layer for specifying weights and other type of parameters. For the manipulating relationship methods, it will also create a group, with the method used being recorded in the group layer. Users could delete the methods by, for example, delete the group layer or move the layers within the group to outside the group.

The bubble design concept works well when there is a method that being repeated apply to different layers. For example, in the design scenario, users have to repeat doing the euclidean analysis method for getting distance to different POIs. By using bubbles, users could reuse the euclidean distance analysis method with already set-up parameters, or combine the euclidean distance and reclassify method as a new bubble and apply them on a new layer. In this way the bubble help reduce repeated works of specifying each methods and applying them to layers when a series of analysis methods need to be applied to multiple layers.

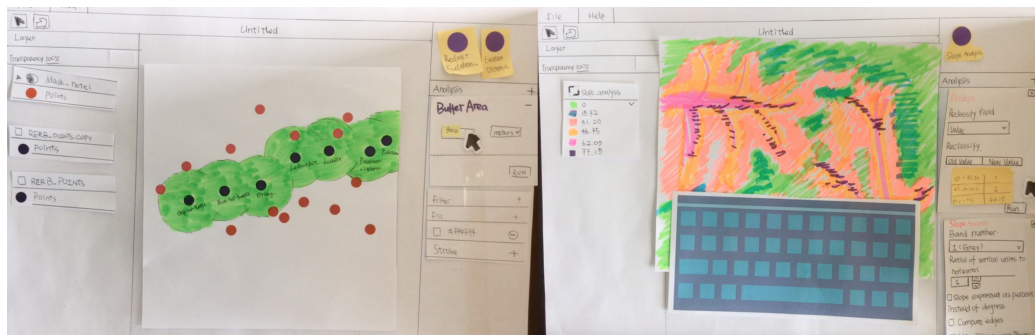


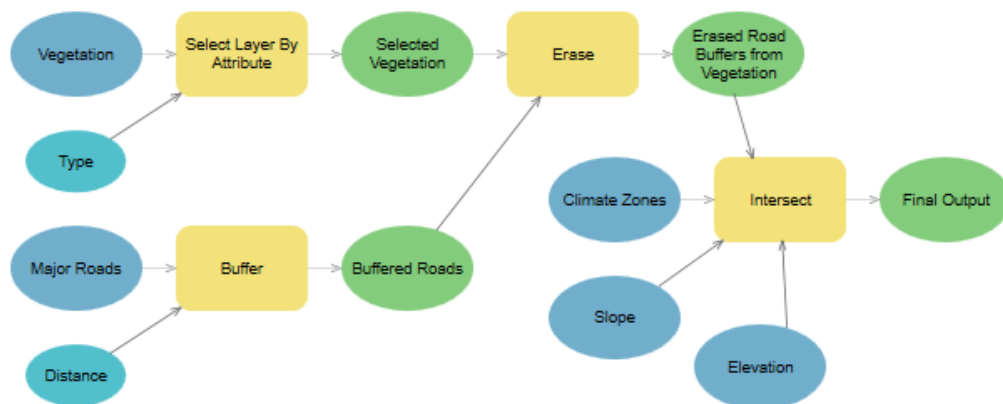
Figure 5.5: Video prototype for the bubble concept

After developing the concept, I made a second video prototype with VideoClipper as shown in Fig 5.5, and evaluate the prototype by viewing at the video with several beginner users. Here are the main drawbacks that I found in the bubble concept:

Bubble helps in reducing repeated work, but the interactions with objects in this system are still mainly based on drop-down menu and pop-up windows. Although the history of analysis method can sustained in bubbles, the only way it allows user to interact their map and data still remains to be typing numbers or selecting options in pop-up windows, which is less direct and less powerful.

After that I also noticed that there is a tool called Model Builder⁴ in ArcGIS as shown in Fig5.6, which works very similarly to Bubble. Arc GIS users specifies a sequence of analysis methods and their parameters in Model Builder before starting the analysis process. After creating a model builder,

⁴<https://pro.arcgis.com/en/pro-app/help/analysis/geoprocessing/modelbuilder/what-is-modelbuilder-.htm>

Figure 5.6: ArcGIS Desktop³

it can be saved as a separate file and be reused to other projects afterwards. Model builder is mainly used by expert ArcGIS users, as it is a function hidden in the menu bars and that it is not very easy to understand and use because it requires a through understanding of analysis methods in ArcGIS. Model builder need to be completed in another interface that has been extracted away from the main map-making interface. As Model builder need to be completed before applying to the data, there is no easy access for users to go back and redo part of its step or delete one step from the final result. However, Model builder do support reuse the pre-determined parameters to different layers of data and eliminates repeated works.

5.5 Final Design: Buffer Region

Different from the previous two design alternatives focusing on the whole process of how users interact with GIS, I am focusing on one how urban planners interact with one specific tool. This idea is mainly based on the three tools that map makers use: buffer area, network analysis and euclidean distance analysis. They are very similar as they all focus on calculating the distance from one point and give the region that can be reached within certain distance. To simplify the design question, I mainly focused on the buffer area tools, as the result of euclidean distance can be stimulated by applying multiple buffer area analysis with different diameters, and the result of network analysis can be achieved by using road networks to replace the diameter for calculating distance. Fig 5.7 shows how buffer area works: urban planners



Figure 5.7: How buffer area works

create this circle with certain boundary and overlap it on top of the original maps, which is called as buffer area. Buffer area helps urban planners to understand what elements are within this defined boundary.

In current GIS software, buffer analysis is conducted by specifying the input layer and diameter in a pop-up window. Fig 5.8 shows the pop-up window for creating buffer area in QGIS. To create a buffer area, users have to first select the input layer and then define parameters for controlling the size and shape of buffer area. If users want to expand the buffer area, they do not have a way to adjust the already-existed buffer area but have to create a new one and redo this whole process. However, as can be seen in the interview, many participants show that when they are conducting analysis task, they are also exploring how they should analyze these data without a clear and direct idea such as "I am looking for the hotels in 1km around me", but instead a very vague idea like "I want to find a hotel that is close to me". Therefore, buffer region is a tool that I designed is trying to provide more support for their exploration process.

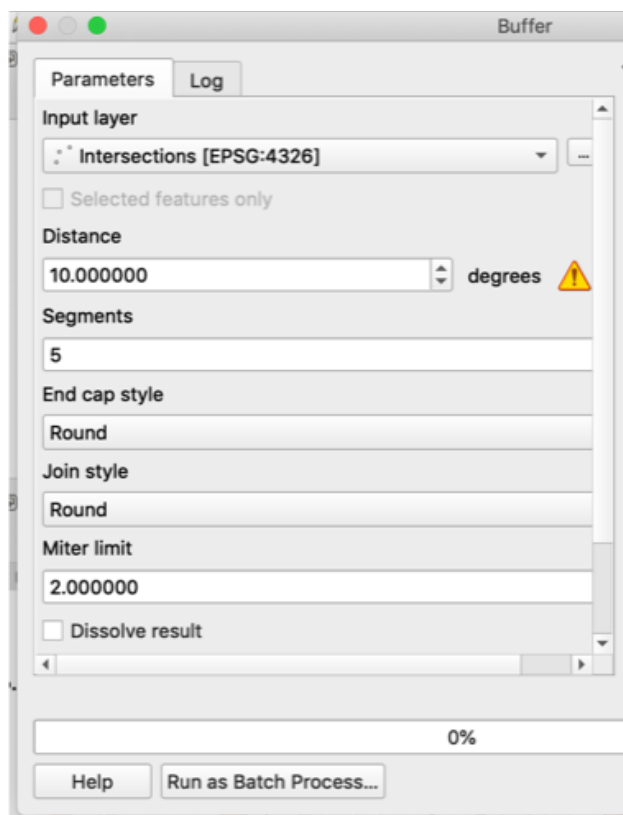


Figure 5.8: Creating buffer area in QGIS

The buffer region is simple and easy to understand. Instead of the current way of selecting buffer area in menu and specify parameters, users can directly create a circle that represents the buffer area, which I called buffer region in their projects. This created circle can be attached to different type of elements, including points, lines and polygon to create a buffer area with determined diameter as shown in Fig5.9 (c). It can also be applied to a single layer, which will create multiple buffer area for all the elements within the layer as shown in Fig5.9 (d).

Users could also combine multiple buffer region and combine them as a new buffer region, with circles with different diameters as shown in Fig5.9(b). This combined buffer region would create multiple buffer area with different diameter specified when it is applied to an element.

To change the diameter of the buffer region, as shown in Fig5.9(a), users could either click the created buffer region and specify the new diameter or

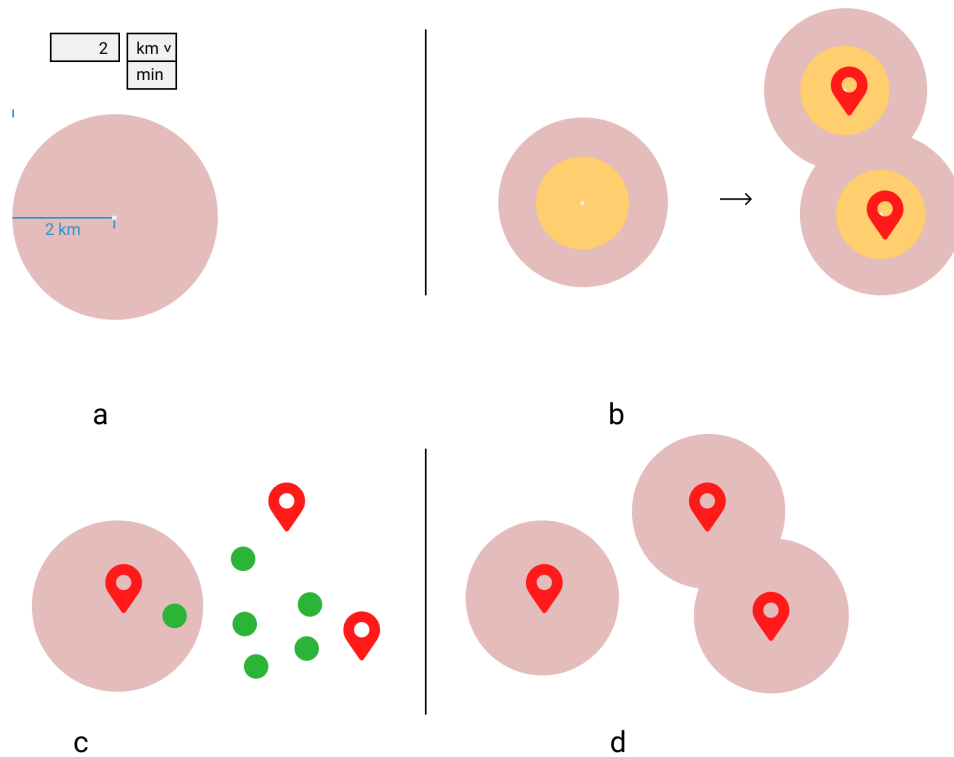


Figure 5.9: Design concept: Buffer region: (a) adjust diameter of created buffer region; (b) apply a combined buffer region to POIs; (c) apply buffer region to one element in the layer; (d) apply buffer region to the whole layer

by drag the boundary of the created circle to adjust its diameter. Users could change the diameter by adjusting the diameter of the created buffer region, or by adjusting the diameter of the generated buffer area. When the adjusted buffer area was originally from a buffer region applied to a layer, it will also change the other buffer area that was generated with the adjusted one. Buffer region supports user task of exploration by allowing users to adjust diameters. For early-career users, and for some tasks when users need to explore the best parameters, they can directly adjust the visual element on map for specifying diameter. This supports users preference of directly manipulating objects on maps. Because users can directly adjust the parameter, they do not need to repeat the task of creating new buffer area and go through every parameters when exploring.

To better support user's analysis task with other criteria such as time, the buffer region also support users to switch between distance and time when adjusting the diameter as shown in Fig5.9. It means that users could create a buffer region for 1 km boundary, and they can also change it into a region for estimated 10-minutes transportation time boundary. This provides an estimation of accessibility based on euclidean distance, which is used by urban planners for their analysis tasks. For example, in the design scenario of building new resort, users would use the distance to estimate transportation time to other POIs instead of using actual road network.

In this tool, users are mainly using overlay as a tool during their analysis process. For example ,when user is trying to find a hotel that is close to the train stop, he would have three separate layers of data: train stops, buffer area generated around the train stops, and points that indicate where are the hotel as shown in Fig5.9 (c). By overlapping the points for hotel on top of the generated buffer area, users would be able to specify which hotels are within the boundary he set up and which are not and therefore complete his task. Buffer region supports user strategy of overlaying for analysis.

Buffer region supports map makers by eliminating the repeated work. Instead of using pop-up windows to create buffer area, users could directly manipulate the diameter of the created buffer region. Such direct manipulation would also support users in their exploration tasks as they are free to adjust the diameter of the buffer area as they wish after having the generated results. Buffer region is originally part of my second video prototype, and has received positive comments when I was presenting it to some entry-level users.

Although there are similar interaction exist in Apple's Map View with which users could directly drag the boundary of a circle, it doesn't support requirements of professional GIS users such as applying to other elements that are not points and adjusting and applying to multiple objects.

I decided to focus on the idea of buffer region and continue my works on implementation and evaluation for the following reason: (1) Buffer region is the idea that with most direct manipulation. It can be used to support users' task of exploration and eliminate repeated work. It is easy to understand and use, while it can be applied to different type of objects.(2) It is a simple and easy to understand tool, but can be used in different scenarios and different tasks while the other two ideas are mainly designed for a problem in a specific scenario. (3) It provide supports to user task of exploration, which

most of the current tool do not support and consider the working process of urban planners to be a one-time issuing task. (4)It can help reduce the repeated works performed by users while exploring. Users do not need to go through the process of creating buffer area every time but could simply modify the created buffer region.

However, with the current design of Buffer Region, users cannot use the actual road network as road input because the current design of interaction does not supports it to identify whether it is applying to a layer, or that it is determining that layer to be the input network for calculation. As a result, users can only perceive a rough analysis result that is simply based on the euclidean distance on maps. Also, for the transportation time, Buffer Region does not support query on different types of transportation tool but simply supports to transfer between distance and time based on average walking speed. Further works needs to be done in order to get more realistic analysis results.

I am interested in how to unify the analysis methods used by map makers as there are certain similarity between them. Although Buffer Region can stimulate three analysis methods and therefore unify these three analysis methods to some extent, there is work that still need to be done in the way that unifying, or applying the basic concept of buffer area to other analysis tools. One example would be the tool that users used for cutting a vector map into grids. Users need to specify the grid size and might also need to adjust it while visualizing the data, to find out the best size for visualization. Also, if think of the buffer region as a symbol that defined by users, it might also be applicable to be used in the reclassify process or help users to customize visualization. There is still works remained for exploring how to expand this concept.

Chapter 6

User Tasks Enabled by Buffer Region

Based on the interview study, there are three scenarios that buffer region could benefit users compare to the current interaction: exploring parameters, changing criteria, creating combined buffer region. In this section I present the storyboard for each scenario to describe how could Buffer Region could better help users in achieving their goals.

6.1 Scenario 1: Explore parameters

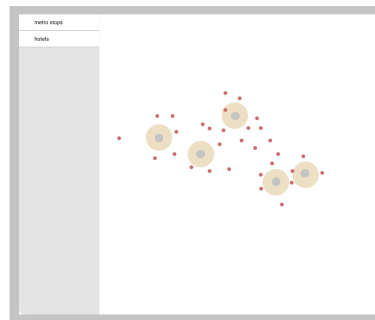
Exploring parameters is one of the very frequent tasks that urban planners preform when exploring new analysis methods or for a query does not have a very strict criteria. Fig6.1 to Fig 6.2 show the scenario of how Aino uses Buffer Region in exploring parameters for finding multiple hotels near the metro stops. In this scenario, with the use of Buffer Region, Aino could directly adjust the region of Buffer Region and see how many hotels are included so that she could find the parameters for her task, with less try and less repeated work of setting up the parameters every single time when creating the buffer areas.

Buffer region allows users to dynamically change the parameters and control buffer region instead of going through the creating process by pop-up windows every time. With the possibility of dynamically changing parameters, buffer region could better supports user task of exploration for following reasons: (1)it helps user to get first-hand feedback on how changing diameters could affect the creating of buffer area; (2) it reduce user tasks of going back and forward for repeating the process of creating new buffer areas when

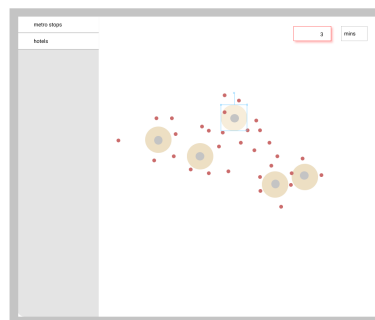
they are not familiar with the tool and when they are exploring parameters to use; (3) It reduce user pressure that they have to remember the previous parameters they used while exploring and trying out new parameters.



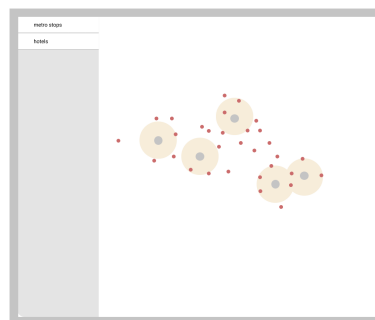
Figure 6.1: Scenario 1: Explore parameters (1)



She created a buffer region with 1-minute walking time as diameter, and apply them on the metro stop layers. She only get 2 hotels that are within the region.



She then expands the buffer region to 3 minutes by dragging the boundary of the circle



She get the amount of hotels she wants.

Figure 6.2: Scenario 1: Explore parameters (2)

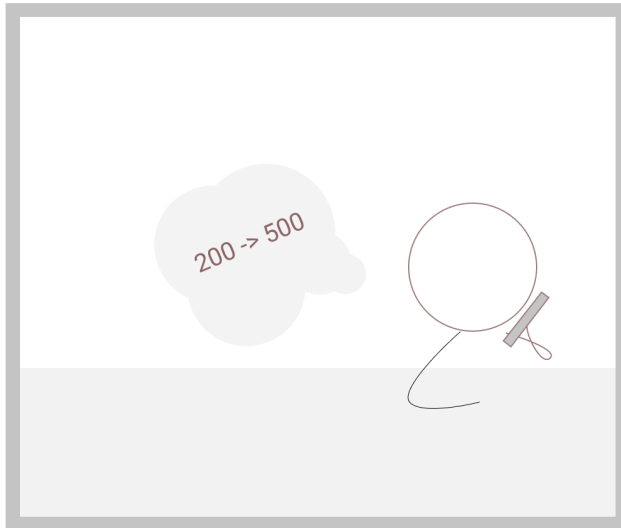
6.2 Scenario 2: Changing criteria

Sometimes some criteria in a project might be changed due to multiple reasons, Fig6.3 - Fig6.4 shows how Buffer Region can help in reducing repeated work when the criteria is changed and users need buffer area with new regions, or apply to newly added objects. When the criteria is changed, users do not need to redo the job, but simply adjust the parameter of already existed buffer areas. Similarly, although it is not shown in the storyboard, users could simply already exist buffer region to the newly added objects, without making a new buffer region.

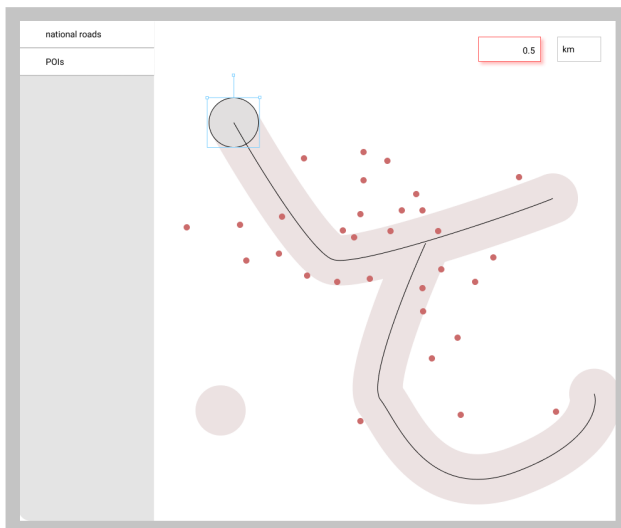
In this user scenario, buffer region could better supports user tasks as when the criteria of buffer region suddenly changed, users will not need to manually create another new buffer area and repeat the step of typing other parameters that remained unchanged and therefore reduce their manual works. Similarly, when only one parameter is changed, users are not required to remember all the parameters they used but simply need to change the parameters that they need to change.



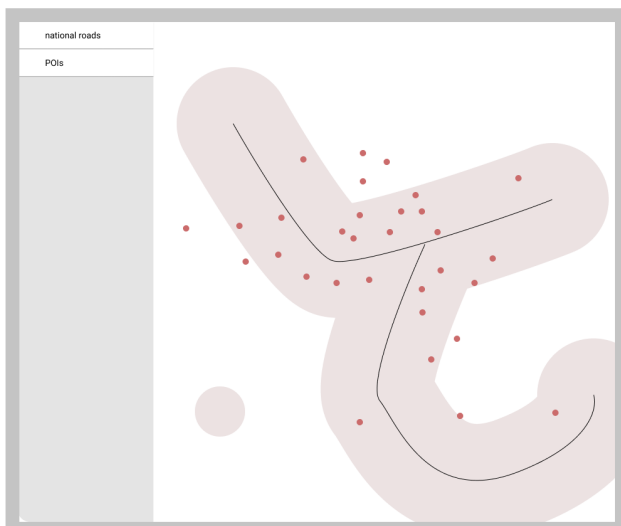
Figure 6.3: Scenario 2: Changing criteria (1)



He is told that the requirements has changed and he should be looking for POIs within 500m



He selected the created buffer area, and adjust its diameter from 200m to 500m by typing in numbers in the input box.



And he gets the boundary of 500m around national roads

Figure 6.4: Scenario 2: Changing criteria (2)

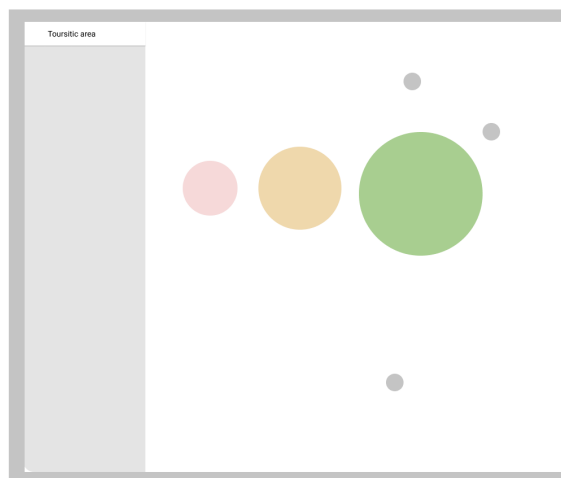
6.3 Scenario 3: Creating combined Buffer Region

This scenario is a simulation of simplified euclidean distance analysis with the use of buffer region. Euclidean distance is one of the popular analysis methods that urban planners use in different types of projects. However, QGIS doesn't provide euclidean distance analysis tools and therefore users would use buffer analysis to achieve similar result, while they have to create multiple buffer areas manually. Fig 6.5 - 6.6 shows how users could use buffer region to achieve a simplified version of euclidean distances. By creating multiple Buffer Region and apply them to the starting point, users could get a rough area of where are within what distance.

This is an example to demonstrate how buffer region could be extended for different analysis method. As there are similarity across different analysis methods, Buffer Region can also be used for supplying different analysis methods. And as this is a relatively direct and easy-to-understand way to demonstrate how the tool is used for, it could also possibly help early-stage users to understand and learn the tool.

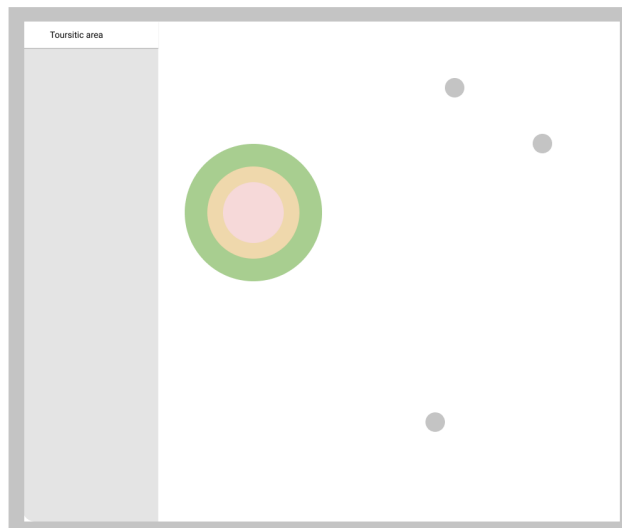


Anne is working on a site analysis project, and she wants to know the distance to touristic attractive from every point on map

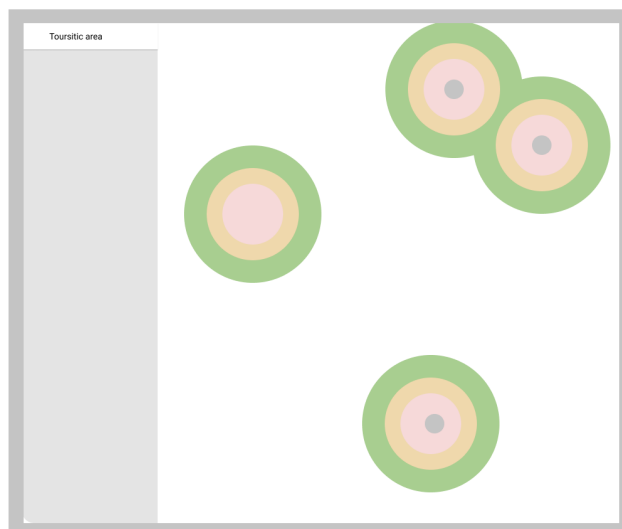


She creates 3 buffer regions with different diameters.

Figure 6.5: Scenario 3: Creating combined Buffer Region (1)



She combines the three buffer regions as a new buffer region, and apply it to the layer with location of touristic attractive



She gets map that display the distance to touristic attractive

Figure 6.6: Scenario 3: Creating combined Buffer Region (2)

Chapter 7

Implementation

I had three options when implementing Bubble Region: (1) Plug-in in QGIS, (2) Web-based application based on actual geographic data and actual data-analysis process, (3) Web-based application with simulated geographic data and simulated data analysis process.

I chose the third option because if I implement it as a plug-in in QGIS, it wouldn't give me freedom to support the interaction that I want it to have such as dragging the buffer region to random position or apply it to elements without using pop-up windows to identify input. I also didn't chose the second one due to the limited time I have for implementation and I want to focus more in the interaction instead of thinking about the analysis methods.

Bubble Region is implemented by HTML + Javascript, using a Javascript library Konva JS¹ for manipulating HTML5 canvas events. The geographic data that I used in Bubble Region as demo is static and cannot be changed.

This implemented Buffer Region has the following main features:

1. **Free drawing buffer region** As shown in Fig7.1, users can draw buffer region at any places on the canvas
2. **Edit buffer region by two ways** Users can adjust the diameter by clicking the buffer region and then indicate the new diameter by typing in the input box or dragging the control box that is around the Buffer Region, as shown in Fig7.1. After creating a buffer region, users could click on it, and there will be a line overlapped on top of the buffer region

¹<https://konvajs.org/>

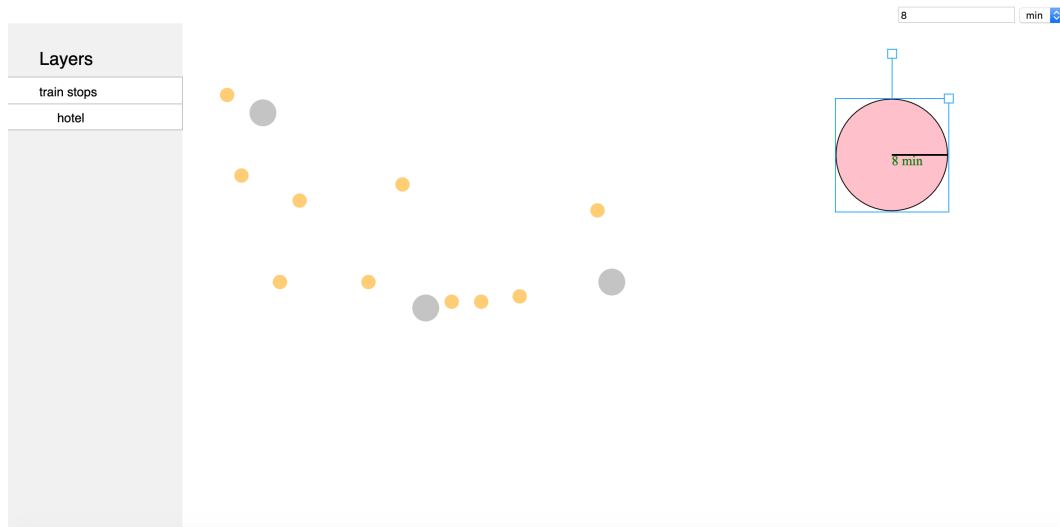


Figure 7.1: Free drawing Buffer Region and adjust diameter by input boxes or dragging

with text under the line that present the value of its diameter. Also, there will be an input box presented at the top-right of the interface with values. Users could change the value of diameter by dragging the blue square presented around the buffer region or directly change the value in the input box and push “Enter” button on keyboard.

3. **Switch between distance and time** As shown in Fig7.1, users are able to switch the meaning of diameter between travel time and distance after clicking on the Buffer Region. After clicking on the Buffer Region, there will be a drop down box and an input box presented at the top-right of the interface. Users could switch the measurement between distance and time by clicking the drop down box, which currently provide the option of “min” and “km” to users.
4. **Apply on single element or the whole layer** As shown in Fig 7.2 and Fig7.3 users can apply defined Buffer Region to both single elements on canvas or to the whole layer. After clicking on a created buffer region, users could drag it onto a single elements to apply it on a single point, line, or region. Users could also drag this selected buffer region onto a layer so that the buffer region is applied to the whole layer and will create buffer areas for every single element within the layer.

The two layers of data are static and cannot be changed, as they are hard

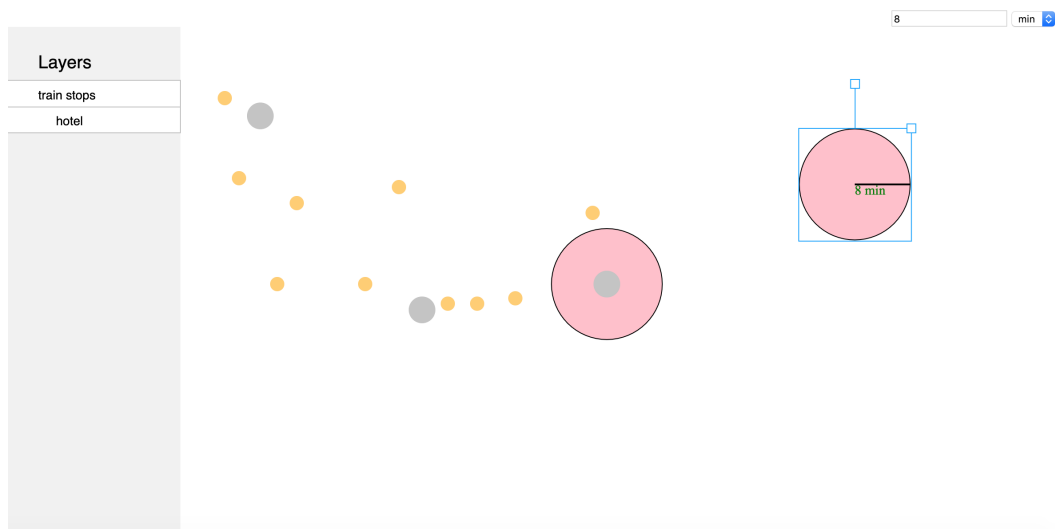


Figure 7.2: Apply Buffer Region to one element

coded as a series of points in JavaScript. Users could create Buffer Region in any area on the canvas. After the buffer area is created, users can click on the circle and there will be diameters shown on the circle, an input box for switch between time and distance and changing the value of diameter, and a blue box for changing its diameter and move its position. The feature of applying Buffer Region to elements or the whole area is realized by the drag event handler provided by Konva JS² and a drop event handler that I defined and customized by myself. When the mouse is dragging a buffer region and when the mouse is over a point, the point will change its color to indicate that it can be applied onto this point when dropped, and the buffer region is applied to the point when dropping it and it will generate a buffer region underneath.

²<https://konva.js.org/>

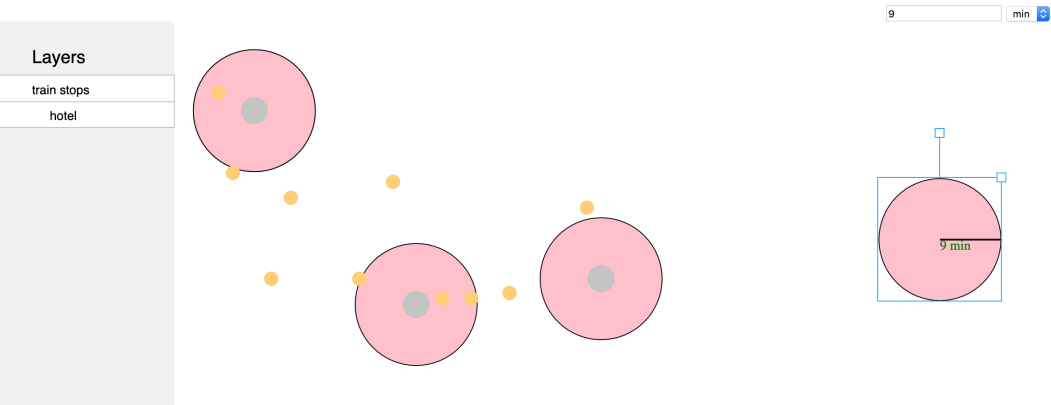


Figure 7.3: Apply Buffer Region to a whole layer

Chapter 8

Conclusions

In my thesis, I focus on what problem professional users have while interacting with GIS and what kind of new tools can be designed for helping them with their professional tasks.

In order to understand the tasks of map makers and problems they have while making maps, I conducted critical object interview with 13 professional users. I find out that map making process is accompanied by the data analysis process. When analyzing and visualizing geographic data, map makers are exploring their data sets and patterns performed on the map. Current tools do not support their exploration well as they consider the analysis process to be a one-time process, so that users need to go back and forward to repeat their works.

I extracted design implications from my interviews and developed 3 alternative design concepts, in which Mask and Bubble are focusing on how analysis methods are applied to data and Buffer Region focusing on reify the buffer area used for analysis tasks. I decided to continue with the Buffer Region concept because it provides a simple yet powerful way for users to interact with the map and can be applied for multiple scenario.

I determined three scenarios that users could use Buffer Region for. The 3 scenarios includes: direct manipulating the diameter of defined buffer region for accomplish spatial analysis task, changing the diameter for exploring data sets, reuse defined buffer area for eliminating repeated works, and applying a group of buffer region to objects to support different tasks.

I implemented Buffer Region as a web application with JavaScript. However, due to the limited time I got, I didn't get chance to evaluate Buffer

Region with users. For future work, it would be necessary to conduct an experiment for testing how well Buffer Region in helping map makers in their exploration tasks.

In the current version buffer area can only be used for creating buffer regions based on euclidean distance, or travel time that is based on the calculation of distance and walking speed. Users are unable to switch between transportation tools for calculating transportation time. Also, although the current system simulated the analysis process of users using buffer region for rough analysis based on euclidean distance, it doesn't support analysis that based on the actual road network. To provide users possibility to acquire more detailed and more realistic result, I should be considering the ability of specifying road network as input and determine transportation type while calculating travel time.

My current system is a simulation of interaction in GIS and the analysis process in GIS. The data that I used in the system is static and users could not specify their focusing area. It would be more realistic by making the tool applicable by either further implement it as a plug-in, or allowing the system to use the data in real world as its input.

Buffer Region is a tool that specially designed for the buffer area analysis method while I am interesting in expanding this concept so that the interaction with different tools in GIS can be unified in a way. Buffer Region is applicable for stimulate 3 analysis methods that professional users used for their tasks: buffer area analysis, network analysis, euclidean distance analysis. However, there is hundreds of tools in ArcGIS that are used by different professional users. To unify them with a simpler interaction, there is still works need to be done. I have been think about expanding the concept that consider the created buffer region as a symbol created by users to control some of the property, for example diameter. This customized symbol can be used in more analysis methods. For example, it can be considered as creating a symbol to identify the grid size when cutting the vector map into grids, and it can also considered to be a reflection on how old values are correlate to new values when reclassify values, or use as a new symbol for customizing visualization. It is still an idea and there is work remained after evaluating Buffer Region and reflect the evaluation results on further shaping this idea.

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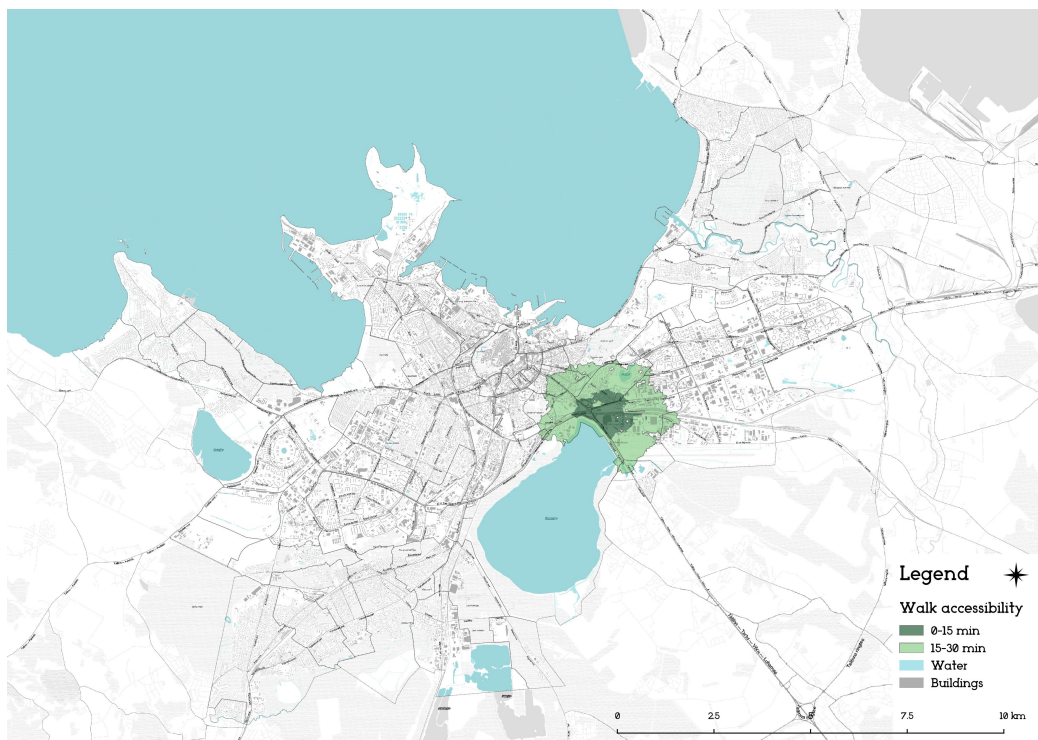
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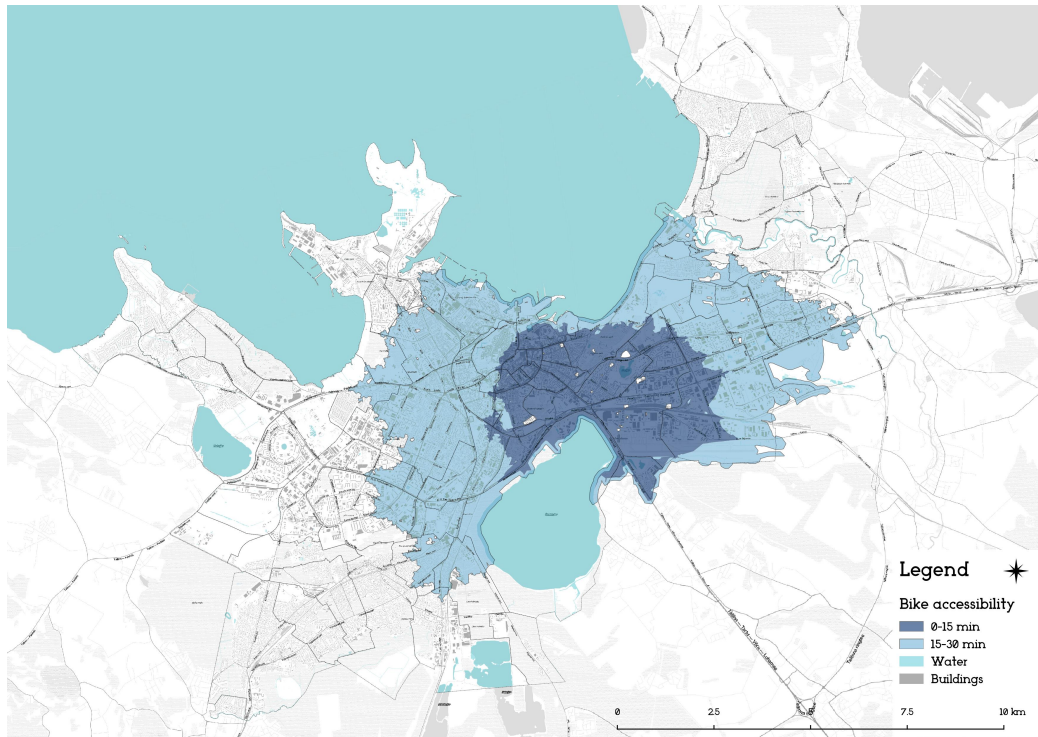
Appendix A

Maps made by participants

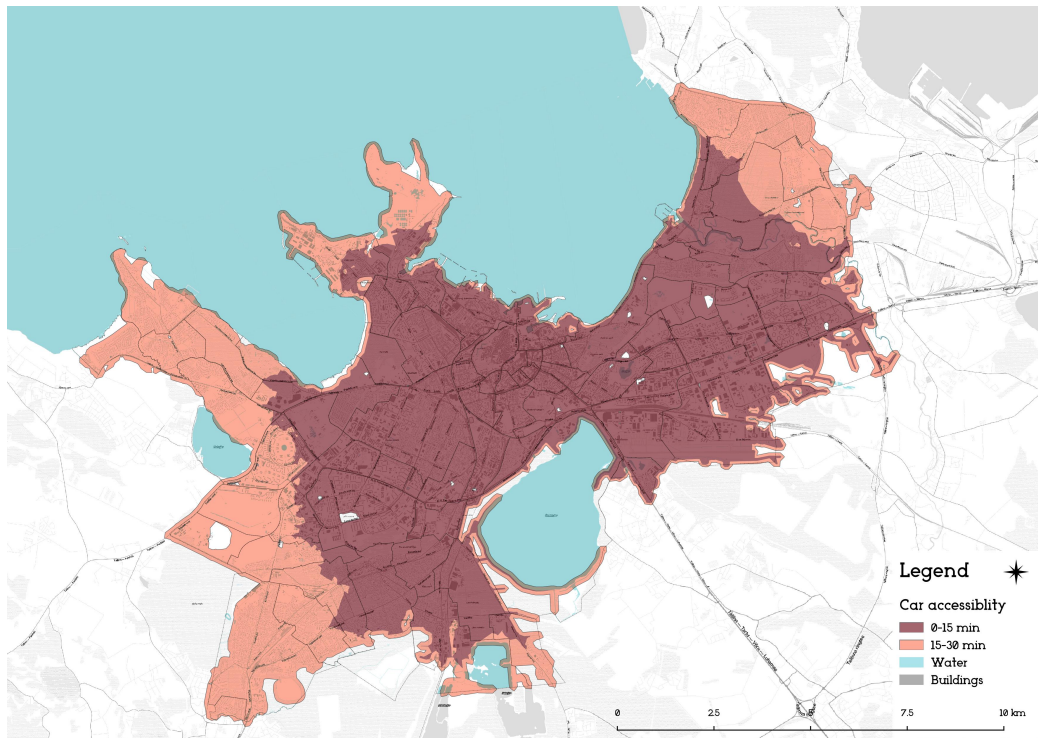
Fig A.1 is a series of map created by P5 for describing transportation accessibility by using different transportation tools. This is completed by separating types of roads into roads for bike, car, and pedestrian and apply network analysis to different categories of roads.



(a) By walk



(b) By bike



(c) By car

Figure A.1: Transportation accessibility maps provided by P5

Appendix B

Consent form, questionnaire and Quick-IRB

Study: *Professional use of GIS software* **ID:** *2019-Coadaptive-Map* **Participant ID:** *P-*

1. Purpose of the study: We are interested in how professional urban city designers currently use GIS software to perform different design tasks which will help inform the design of a new, easier but more powerful geographic information system.

2. Procedures to be followed: If you agree to participate, we will ask you to show us a current GIS project, and ask you to show use how you used the software to solve specific design problems. We are particularly interested in breakdowns, where the software does not perform as it should, as well as innovative uses of the tools. If possible, we would appreciate copies of GIS designs, but not if the material is confidential. We will audio or video record the interview.

3. Risks and Discomforts: We do not believe you will experience any risks by participating in this study, beyond those in daily life.

4. Benefits: You may find new ways of drawing your map or working with GIS software.

5. Duration: The complete study, including pre-questionnaire and interview will take about 30-45 minutes.

6. Confidentiality: Your participation in this research is confidential and your data will be anonymized, so that it cannot be traced to you. Anonymized results from the study may be published in a research article, either in summary form or as anonymized quotations. We may publish or present screen recordings or images that you shared with us, but will not include any personally identifiable information. The researchers listed below will be able to review the anonymized data:

Wendy Mackay	Research Director	Inria	mackay@lri.fr
Yuyan Jing	Master Student	Inria	jing@lri.fr

7. Right to ask questions: Members of the research team will be happy to answer any questions about research procedures and future publications. You may contact *Yuyan Jing* (jing@lri.fr) or *Wendy Mackay* (mackay@lri.fr) if you have questions, complaints or concerns or Inria's ethics board (COERLE) if you feel this study has harmed you in any way:

<http://www.inria.fr/institut/organisation/instances/coerle/composition>

8. Voluntary Participation: Your decision to be in this research is entirely voluntary. You do not have to answer the questions, and you may ask us to withdraw your data from the analysis, up to two months after the study. You may stop at any time, without giving a reason, and there is no penalty for withdrawal. You will not be paid for taking part in this study.

9. CONSENT: You must be at least 18 years to participate in the study. If you agree with the above, please sign your name and indicate the date. You may ask for a copy of this consent form.

Study: *Professional use of GIS software* **Study ID:** *2019-Coadaptive-Map* **Participant ID:** *P-*

The nature and purpose of this research have been sufficiently explained and I agree to participate in this study. I understand that I am free to withdraw at any time without incurring any penalty.

Participant's name	Signature	Date
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Researcher's name	Signature	Date
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☐ Check here if you would like to receive a copy of a publication that results from this research.

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE
Centre Inria Saclay – Île-de-France

Bâtiment Alan Turing – 1 rue Honoré d'Estienne d'Orves – Campus de l'École Polytechnique
91120 Palaiseau, FRANCE

Établissement public national à caractère scientifique et technologique - Décret n° 85.831 du 2 août 1985

Quick IRB proposal

Members of the research team explicitly agree to the following conditions:

1. Review the informed consent form with each participant to ensure that they understand that:
 - they will not receive financial compensation for their participation;
 - they may leave the study at any time, without having to give a reason;
 - they may decide not to show particular personal data or authored works, without having to give a reason;
 - the study does not pose any risks or discomforts beyond slight fatigue or boredom;
 - their raw data will be anonymized, and their personal identifying characteristics will be stored separately by a designated research team member;
 - non-aggregated, but anonymized, data will be accessible to research team members listed on the informed consent form;
 - performance data will be published as anonymized examples or in aggregate form;
 - individual quotes, images or work will only be published in anonymized form;
 - any copyrightable artistic or scientific work will only be published with the participant's explicit permission and acknowledgment;
 - they may obtain additional information about the study, including any future publications, by contacting a specified researcher; and
 - they may complain about any aspect of the study to the Inria COERLE board.
2. Prior to running the study, obtain an approved, signed informed consent form from every participant, and give them a copy for their records.
3. Protect the identity of each participant by labeling all raw performance, interview, and questionnaire data with a participant code, to be used for all subsequent data analysis. Ensure that one research team member maintains the mapping between the participant code and the participant's personal information, stored separately.
4. Ask for explicit permission to reproduce copyrightable material, usually in the form of images or video, from artists and scientists, including paintings, music compositions, sketches, designed objects; laboratory notebooks.
5. Complete the attached study description and informed consent forms. Instructions and items to complete are in italicized text; non-italicized text should be included directly.

Quick IRB proposal

Professional use of GIS software

Interview with urban planners using GIS software to perform different design tasks which will help inform the design of a new, easier but more powerful geographic information system. MoveOn

Research team

Principal investigator	MACKAY Wendy	Research director, INRIA	wendy.mackay@lri.fr	
Contact investigator	Yuyan Jing	Master student, Université Paris-Sud	jing@lri.fr	

Funding

Ethics Review

Study Description

This study is a semi-structured interview with GIS software users. The purpose of this study is: 1) to understand the design task that users perform in GIS software and what current system cannot fulfill their requirements, 2) to figure out design possibilities with the design tasks that professional users perform in achieving their goals

Procedure

This study is divided in 2 parts.

1. Introduction of the study and pre-questionnaire. Participants are asked to fill a pre-questionnaire about their background, the software they use, and their experience with the software.
2. = We will ask the participants to show us their recent work and introduce us the background of their piece of work, and steps they took for accomplishing their work. After that, we will ask participants to talk about problems they met during the process as well as throughout their use of the software. After that, we will ask about other tools they use while working with their project.

Duration

The interview will last for around 35-45 minutes, including 5 minutes of introduction and filling in pre-questionnaire, 30 - 40 minutes of interview.

Data collection

We will audio or video record the study. We will also collect screenshots, photo, or project file of participants' work with GIS software that participants mentioned during the interview.

Data protection

Every participant will be assigned a unique participant identifier that is associated with all raw data, including performance data, audio and video records or answers to interviews and questionnaires. The contact investigator, *Yuyan Jing*, will maintain a separate list of participant identifiers and participant names and information that will not be accessible to other investigators. The research team members, listed above, may review all data records related to this research study, but without personal identifiers.

The principal investigator, MACKAY Wendy, will store and secure the data in a locked cabinet, in a locked office. The research team members may review all anonymized records related to this study. All publications and presentations resulting from this research will present either anonymized quotations from questionnaires or interviews, anonymized examples of specific trials or work, or aggregate quantitative data, with no personal identifiers.

Risks and discomforts

We believe that our study does not contain any direct risks to our participants.

Benefits

Participants will not receive any benefits or financial compensation for participating in the study.

Voluntary participation

Participants will be informed that their participation is voluntary and that they can stop at any time, without providing a reason, and that their refusal will not result in any penalties. Participants will be informed that they may refuse to show any personal data or copyrightable, authored material, without giving a reason and with no penalties.

Right to ask questions

Participants may contact Yuyan Jing with complaints, questions, suggestions, or concerns about this research, or to ask for a publication resulting from the study. They may also contact the Inria COERLE ethics board if they feel the study has harmed them in any way:

<http://www.inria.fr/institut/organisation/instances/coerle/composition>

Consent

Participants must be 18 years of age or older. One research team member will explain the informed consent form to the participant, answer any questions and obtain the participant's signature before conducting the study. Participants will be given a copy of the consent form, with contact information for any follow-up questions or concerns.

Signatures

We the undersigned agree to abide by the terms of the Quick IRB (Saisine Générique) and to inform the COERLE if any issues arise that exceed these terms.

Principal investigator

Signature

Date

Co-investigator

Signature

Date

Pre-Questionnaire

1. Background Information

Participant Number : <i>This will be filled by interviewer</i>
Age
Occupation
Your Contact <i>Leave your email address if you would like to take part in further study</i>

2. Experience with GIS software

2.a. What GIS software do you use?

☐ Arc GIS ☐ MapInfo ☐ QGIS ☐ Other, _____

2.b. How often do you use GIS software?

- ☐ Almost Every day
- ☐ A few times a week
- ☐ A couple of times a month
- ☐ Rarely

2.c. How long have you been using GIS software?

- ☐ 1 - 3 months
- ☐ 4 months - 1 years
- ☐ 1 - 4 years
- ☐ 4 years +